Technical Report CERC-96-8
September 1996

US Army Corps of Engineers
Waterways Experiment Station

Monitoring Completed Coastal Projects Program

Periodic Inspection of Burns Harbor North Breakwater, Indiana

Report 1
Base Conditions

by Robert R. Bottin, Jr., WES
Erik W. Matthews, Chicago District

Prepared for Headquarters, U.S. Army Corps of Engineers

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Coastal Projects Program

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Report 1 of a Series

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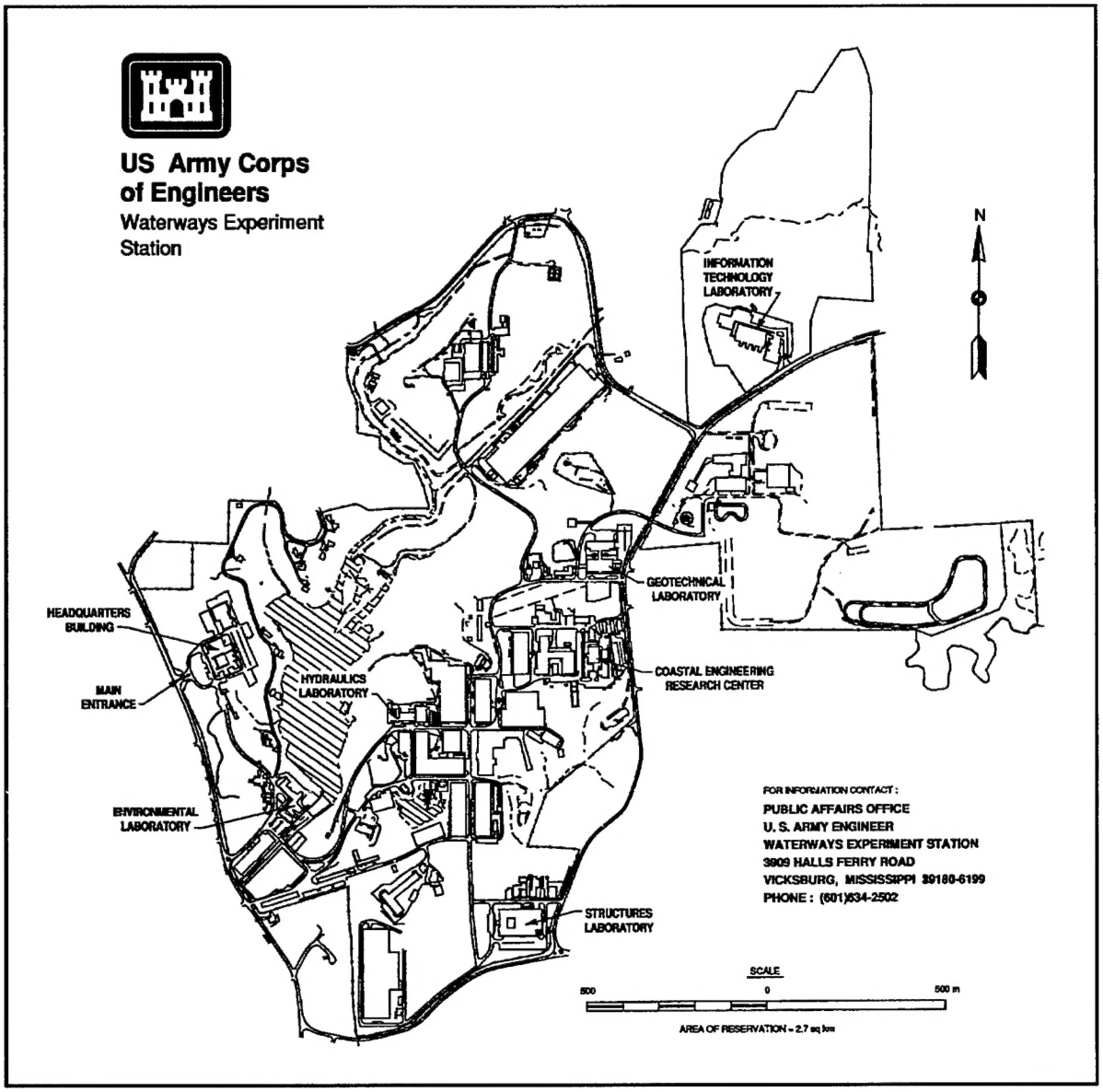
Under Work Unit 22121



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Preface

The study reported herein was conducted as part of the Monitoring Completed Coastal Projects (MCCP) program. Work was carried out under Work Unit 22121, "Periodic Inspections." The Hydraulic Design Section of Headquarters, U.S. Army Corps of Engineers (HQUSACE), is responsible for overall program management for MCCP. The Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station (WES), is responsible for technical and data management and support for HQUSACE review and technology transfer. Program Monitors for the MCCP program are Messrs. John H. Lockhart, Jr., Barry W. Holliday, and Charles B. Chesnutt, HQUSACE. The Program Manager is Ms. Carolyn M. Holmes, CERC.

This report is the first in a series that will track the long-term structural response of the Burns Harbor, Indiana, North Breakwater to its environment. The information contained in this report was gathered as a result of land and aerial survey work conducted by Ocean Surveys, Inc., Old Saybrook, CT, and Western Air Maps, Inc., Lenexa, KS, under contract to the Corps of Engineers, and broken armor unit surveys conducted by Messrs. Robert R. Bottin, Jr., and Larry R. Tolliver, Wave Processes Branch, Wave Dynamics Division, CERC, and Mr. Erik W. Matthews, U.S. Army Engineer District, Chicago (CENCC).

The work was conducted during the period November 1994 through July 1995 under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, respectively, CERC, and under direct supervision of Messrs. C. E. Chatham, Jr., Chief, Wave Dynamics Division, and Dennis G. Markle, Chief, Wave Processes Branch. This report was prepared by Mr. Bottin, CERC, and Mr. Matthews, CENCC.

Director of WES during the investigation and publication of this report was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in figures, plates, and tables of this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	25.4	millimeters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Work Unit Objective and Monitoring Approach

The objective of the Periodic Inspections Work Unit in the Monitoring Completed Coastal Projects (MCCP) program is to periodically monitor selected coastal navigation structures to gain an understanding of the long-term structural response of unique structures to their environment. These periodic data sets are used to improve knowledge in design, construction, and maintenance of both existing and proposed coastal navigation projects. These data also will help avoid past design mistakes that have resulted in structure failure and/or high maintenance costs. Projects monitored in the past under the MCCP program and/or structures with unique design features that may have application at other sites are considered for inclusion in the periodic inspections monitoring program. Selected sites are presented as candidates for development of a periodic monitoring plan. Those sites receiving favorable response during MCCP program review are inspected, and a monitoring plan is developed and presented for approval. Once the monitoring plan for a site is approved by the field review group and funds are provided, monitoring of the site is initiated. Normally, base conditions are established and documented in the initial effort. The site then is reinspected on a periodic basis (frequency of surveys is based on a balance of need and funding for each monitoring site) to obtain long-term structural performance data.

Relatively low cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection tools used in the monitoring efforts. Most periodic inspections consist of capturing above-water conditions of the structure at periodic intervals using high-resolution aerial photography. A visual comparison of periodic aerial photographs is used to gauge the degree of in-depth analysis required to quantify structural changes (primarily armor unit movement). Data analysis involves using photogrammetric techniques developed for and successfully applied at other coastal sites. At sites where local wave data are being gathered by other projects or agencies and acquisition of these data can be made at a relatively low cost, wave data are correlated with structural changes. In areas where these data are not available, general observations and/or documentation of major storms occurring in the locality are presented along

with the monitoring data. Ground surveys are limited to the level needed to establish accuracy of the photogrammetric techniques.

When a coastal structure is photographed at low tide, or low lake levels, an accurate permanent record of all visible armor units is obtained. Through the use of stereoscopic photogrammetric instruments in conjunction with photographs, details of structural geometry can be defined at a point in time. By direct comparison of photographs taken at different times, as well as the photogrammetric data resolved from each set of photographs, geometric changes (i.e., armor unit movement and/or breakage) of the structure can be defined as a function of time. Thus, periodic inspections of the structures will capture permanent data that can be compared and analyzed to determine if structure changes are occurring that indicate possible failure modes and the need to monitor the structure(s) more closely. The Burns Harbor, Indiana, North Breakwater was nominated for periodic monitoring by the U.S. Army Engineer District, Chicago.

Project Location and Brief History

Burns Harbor, Indiana, is a man-made harbor located on the southern shoreline of Lake Michigan, approximately 32.2 km (20 miles)[1] southeast of Chicago, IL (Figure 1). The harbor was constructed primarily to facilitate shipping from the steel industry in northern Indiana. The project was authorized by the River and Harbor Act of 27 October 1965. Breakwater construction was completed in September 1968, and harbor dredging was completed in August 1970.

The harbor project (Figure 2) consists of north and west breakwaters with an aggregate length of 1,780 m (5,840 ft), a 122-m-wide, 9.1-m-deep[2] (400-ft-wide, 30-ft-deep) approach channel, an 8.5-m-deep (28-ft-deep) outer harbor area, a 670-m-long, 189-m-wide, 8.2-m-deep (2,200-ft-long, 620-ft-wide, 27-ft-deep) east basin, and a 1,173-m-long, 189-m-wide, 8.2-m-deep (3,850-ft-long, 620-ft-wide, 27-ft-deep) west basin.

The Burns Harbor structure includes a 1,414-m- (4,640-ft-) long rubble-mound north breakwater with an east-west alignment, a 366-m- (1,200-ft-) long rubble-mound west breakwater with a north-south alignment, and a

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[1] Units of measurement in the text of this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in figures in this report to SI units is presented on page vi.

[2] All elevations (el) and depths cited herein are in meters (feet) referred to low-water datum (lwd), el 175.8 (576.8) above mean water level at Father Point, Quebec (International Great Lakes Datum, 1955).

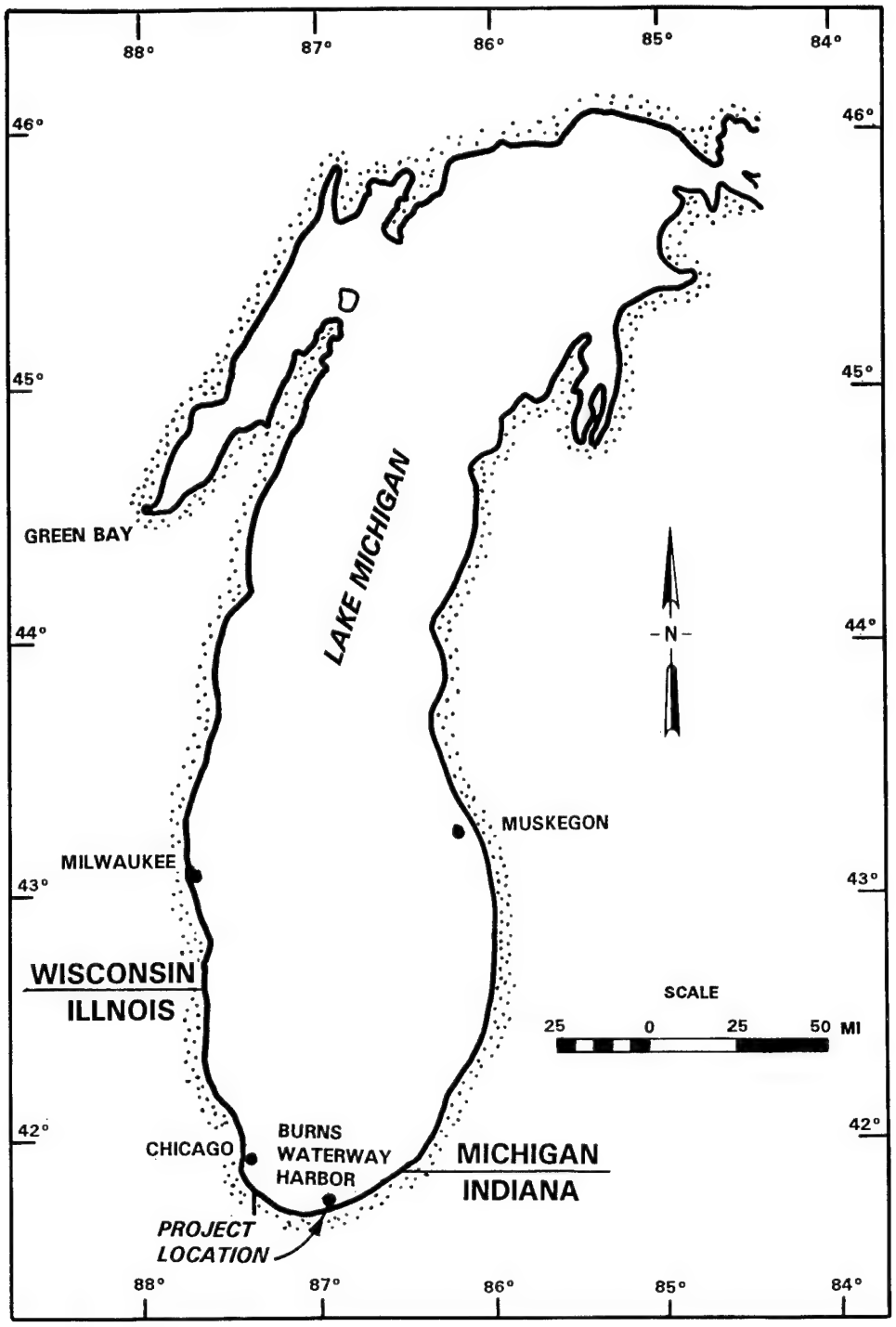


Figure 1. Project location

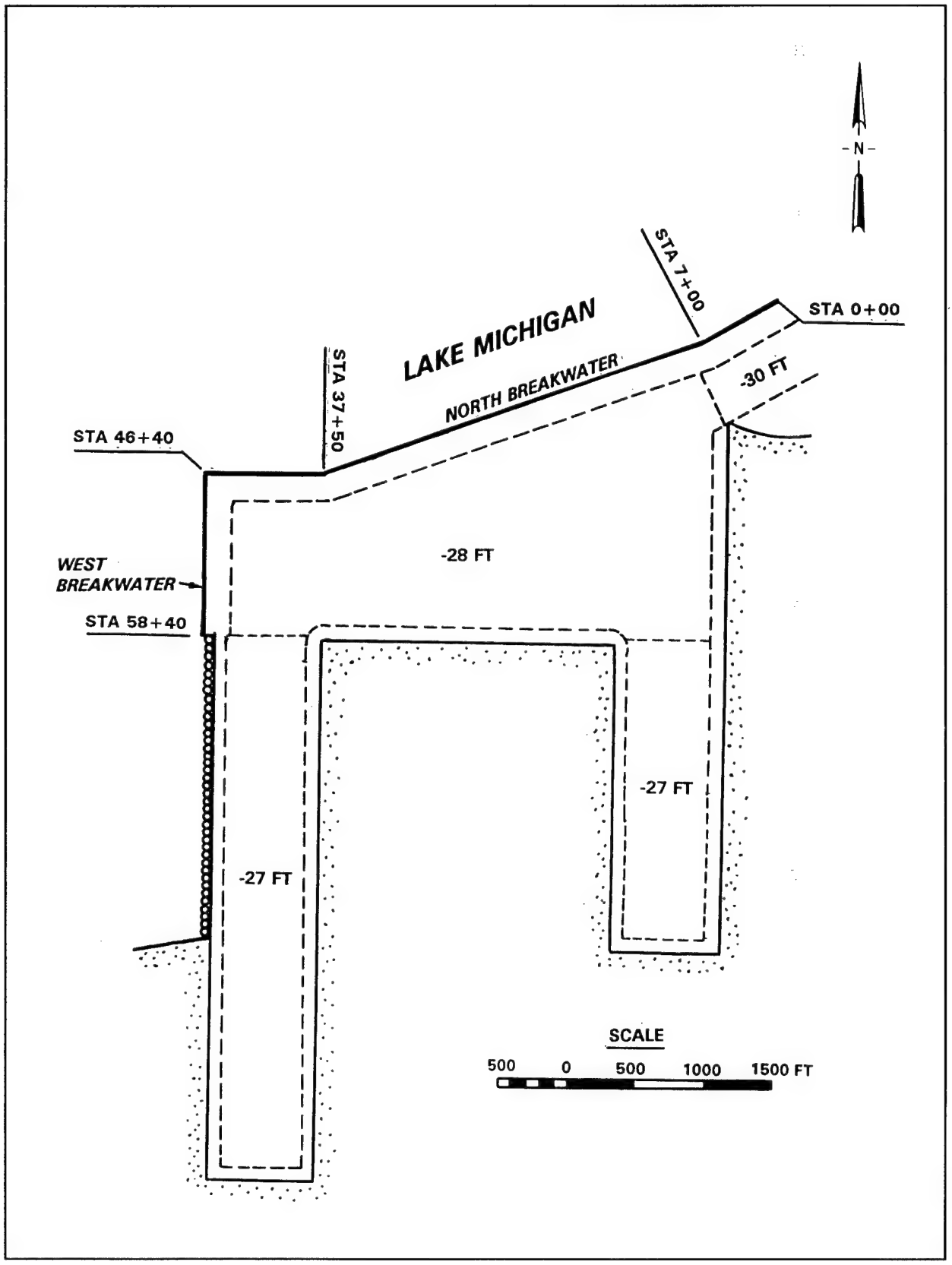


Figure 2. Layout of Burns Harbor, Indiana

cellular steel sheet-pile extension connecting the west breakwater to shore. An aerial photograph of the harbor is shown in Figure 3.

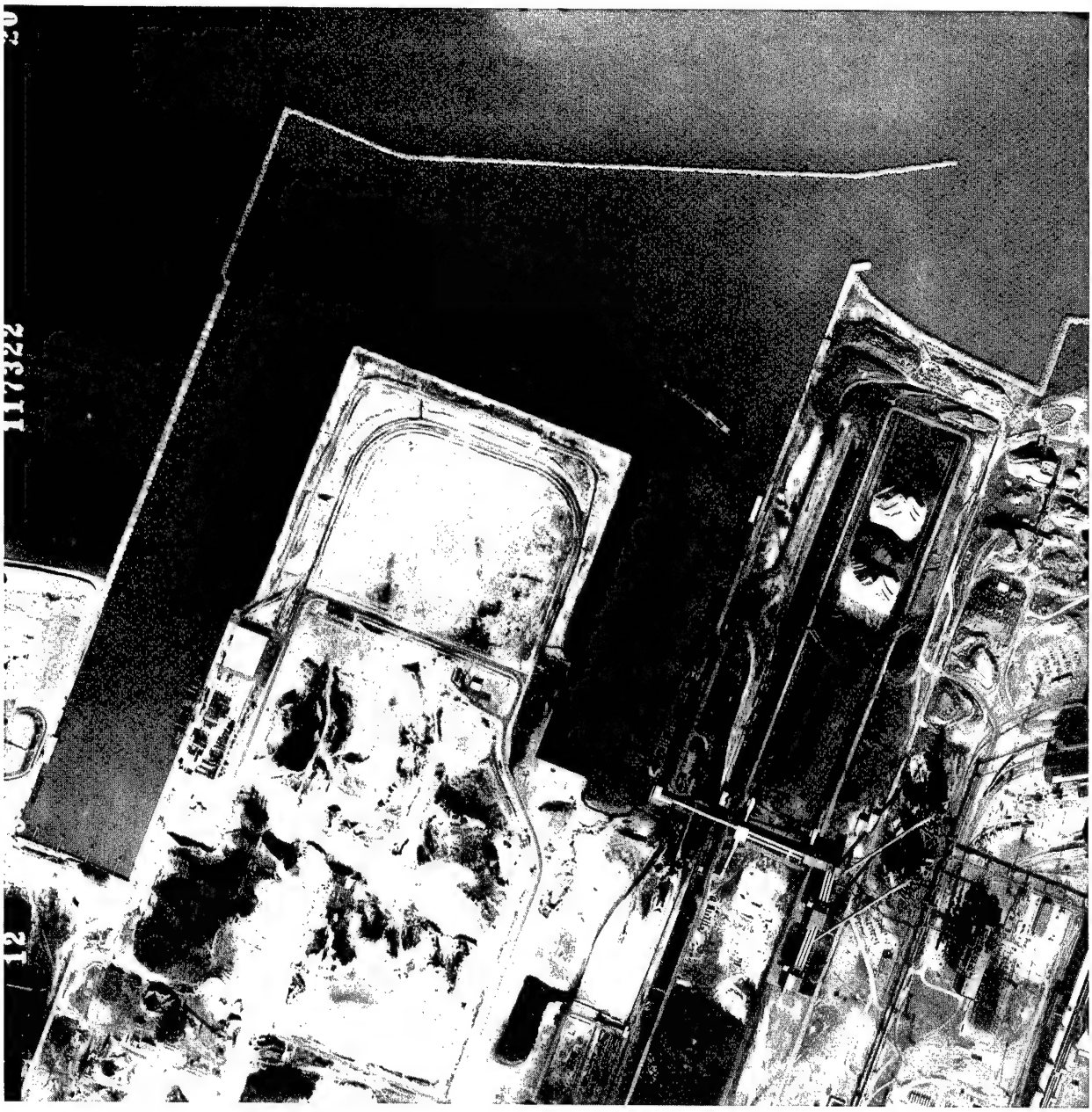


Figure 3. Aerial view of Burns Harbor

The rubble-mound breakwater was constructed with a multi-layered design and random placement of the armor stone cover layers. The crest elevation of the structure was +4.3 (+14) and the toe elevation was approximately -12.2 (-40). Armor stones consisted of rectangular cut Indiana Bedford limestone blocks ranging from 9,100 to 13,600 kg (10 to 15 tons) on the trunk (Figure 4) and 13,600 to 18,100 kg (15 to 20 tons) on the head. A cross section of the original breakwater is shown in Figure 5.

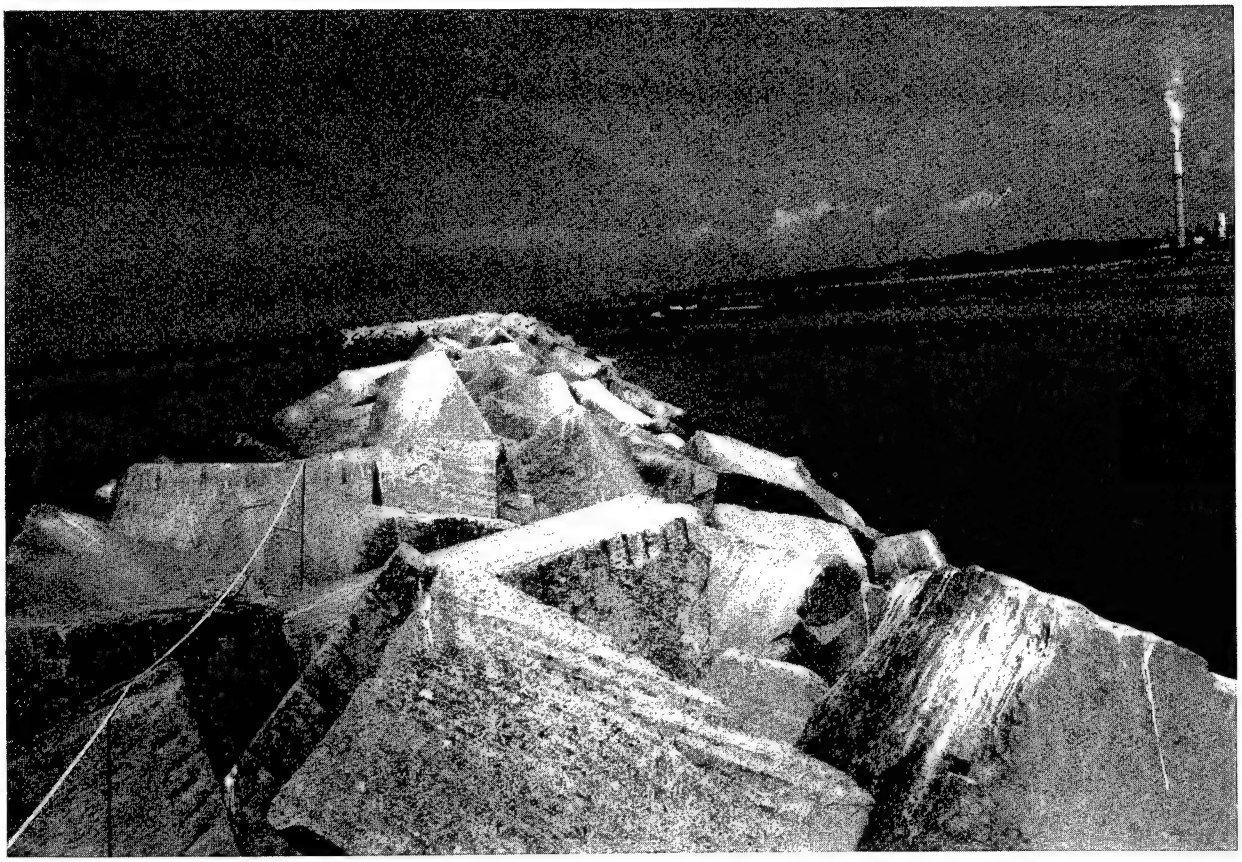


Figure 4. View of armor stone on breakwater trunk

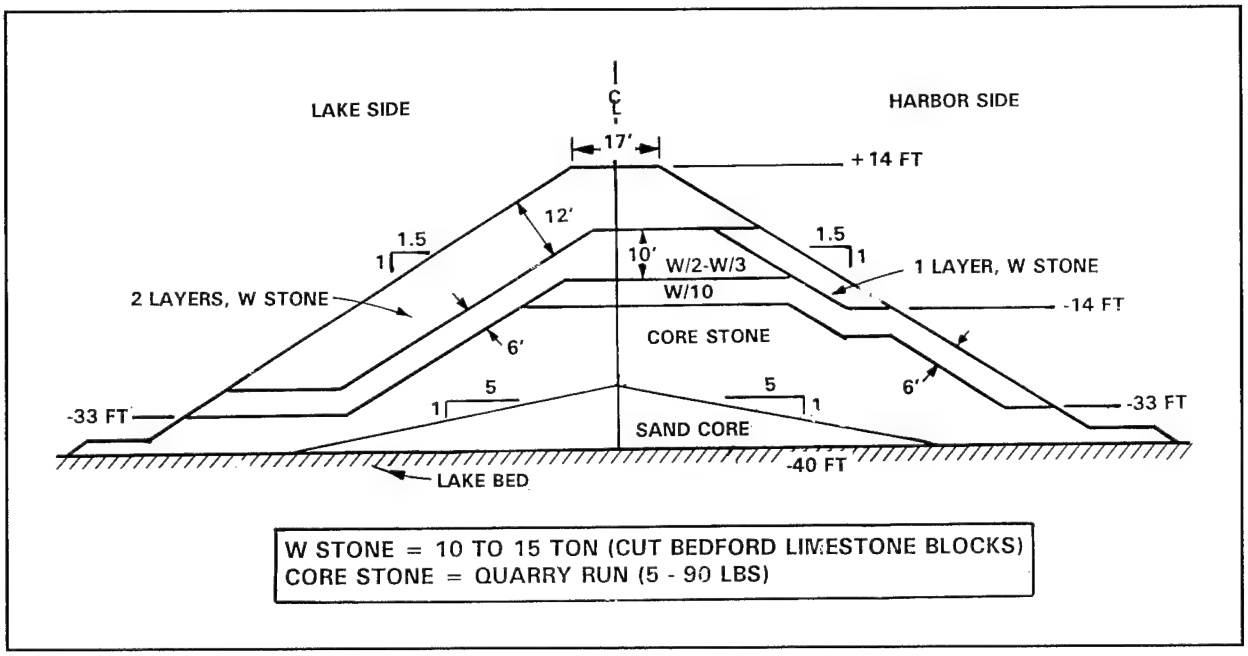


Figure 5. Cross section of original Burns Harbor breakwater

Since completion of construction, extensive breakwater damage has occurred. Maintenance of the crest elevation and structure cross section has required the addition of large amounts of stone. In the first 19 years of operation, an average of 693,100 kg (7,640 tons) of stone per year has been placed on the breakwater. Between 1975 and 1989, the total amount of maintenance stone placed on the structure was 131,647,900 kg (145,117 tons), representing 54 percent of the entire armor layer stone (U.S. Army Engineer Division (USAED), Chicago 1994). The harbor-side and lake-side portions of the breakwater received approximately the same proportions of stone. More information on the rehabilitation history of the structure can be obtained in Bottin (1988).

In addition to continual breakwater damage, the Port Authority of Burns Harbor has reported that port infrastructure and moored vessels have experienced significant damage and downtime during winter storms equal to or less than the expected annual (1 year) event. Barges have broken their moorings and been damaged, two vessels and two barges have sunk while moored to the dock, and damage to north-facing revetments has occurred.

Purpose of the Study

The purposes of the study reported herein were as follows:

a. Develop methods using limited land-based surveying, aerial photography, and photogrammetric analysis to assess the long-term stability response of the stone armor layer on the Burns Harbor North Breakwater.

b. Conduct land surveys, broken armor stone inspections, aerial photography, and photogrammetric analyses to

(1) Test and improve developed methodologies and accurately define armor unit movement above the waterline.

(2) Establish base conditions for the breakwater's armor units that can be revisited in the future under the Periodic Inspections Work Unit.

Prior Studies of the Site

Past monitoring efforts

The Burns Harbor North Breakwater was selected for monitoring under the MCCP program in 1985. The program has as its goal the advancement

of coastal engineering technology. It is designed to determine how well projects are accomplishing their purposes and are resisting attacks of the physical environment. The nomination of Burns Harbor for inclusion in the MCCP program stressed the continuing need to maintain the crest elevation of the breakwater as the principal problem with the structure. The assumption at that time was that the loss of elevation was associated with either foundation failure or inadequate armor stone stability, or both. The Burns Harbor North Breakwater monitoring plan focused on collecting information in three technical areas: (a) structural stability, (b) geotechnical stability, and (c) waves and water levels.

In addition to the three technical areas, the monitoring study was divided into three subtasks: historical review, data collection, and data analyses and synthesis. Historical review involved collecting, indexing, and analyzing all data and records obtained before commencement of the study. Data collection entailed acquiring new information, and data analysis included reduction and analysis of the data collected. Synthesis involved manipulation of either historical or new data, or both, to address an issue.

Data collection for the monitoring program at Burns Harbor occurred from 1985 to 1989. The monitoring program incorporated the use of several observational, direct measure, and remote sensing methodologies. It included site inspections, dive inspections, side-scan sonar surveys, geotechnical data collection, and wave and water level data collection. Results of this study are presented by McGehee and Moritz (in preparation).

Recent modeling efforts

The wave transmission and breakwater stability problems at Burns Harbor were recently investigated in a 1:36-scale, two-dimensional model at the U.S. Army Engineer Waterways Experiment Station (WES) (Carver, Dubose, and Wright 1993). Various repair options were evaluated that included placing submerged reef breakwaters lakeward of the existing structure, attaching a berm breakwater to the lakeside of the structure, adding a 16,330-kg (18-ton) angular stone overlay, and reworking the existing stone into special placement at the crest. Generally, the submerged breakwater and restacking of the existing armor were the least effective approaches to reducing wave transmission, whereas the toe berms and large-stone overlays were the most effective. However, the submerged reefs proved to be the most effective in reducing or eliminating damage to the existing breakwater.

Subsequent to this study, additional two-dimensional model testing was conducted to determine the optimum cross section of a proposed reef breakwater located lakeward of the existing structure (Carver and Wright 1995). Specifically, it was desired to quantify performance (stability/transmission response) in terms of structure height and width, location relative to the existing breakwater, and stone size and gradation. Seven

improvement plans were considered, and all of them significantly improved stability of the existing breakwater and reduced transmitted wave heights in the harbor to some extent.

A three-dimensional model study was conducted at a 1:75-scale to determine the optimum layout (width, length, and spacing of the reef breakwater segments as well as the distance between the toes of the existing and reef structures). Five improvement plans were studied before an optimum segmented reef layout (considering wave protection and costs) was selected. These results are presented in Acuff and Bottin (1995).

As a result of these two- and three-dimensional model investigations, the Chicago District developed a detailed design memorandum (USAED, Chicago 1994) for construction of a segmented reef breakwater lakeward of the existing north structure at Burns Harbor. The reef breakwater should reduce wave energy reaching the existing structure, thus minimizing breakwater damage as well as decreasing transmitted wave heights through the structure into the harbor. Construction of the reef structure is scheduled for the 1995-1997 construction seasons on Lake Michigan.

2 Monitoring Plan and Data

The objective of the monitoring effort under the Periodic Inspections Work Unit was to establish base level data with which long-term stability response of the Burns Harbor North Breakwater could be determined through periodic inspections. The entire 1,414-m- (4,640-ft-) long North Breakwater was monitored. The monitoring plan consisted of targeting and ground surveys, aerial photography, photogrammetric analysis of armor units above the waterline, and a broken armor stone survey.

The Chicago District was in the process of negotiating a contract for targeting and ground surveys, aerial photography, and a photogrammetric analysis of armor units when the MCCP program monitoring commenced. The MCCP program, therefore, used the deliverables from the District efforts for this study with additional analysis conducted by the contractors (Western Air Maps, Inc.). Efforts by the Chicago District also included underwater surveying of the breakwater as well as merging of the subsurface and surface data from which breakwater cross sections were developed. Only the above-water data were used in this report (except for an example shown later) since subsequent periodic inspections of the breakwater will involve only above-water data for comparison. Hard copies of the entire breakwater cross sections (both subsurface and surface data), as well as data stored in Intergraph files, however, are on file with the authors.

Targeting and Ground Surveys

Existing monuments in the vicinity of the harbor were used to serve as reference points (both horizontal and vertical reference) for the ground-based survey work as well as photogrammetric work. Ground surveys were initiated from these monuments. In addition, photo control points were established using global positioning system (GPS) control surveying and electronic land surveying techniques. The existing monuments were bronze disks, cemented into place, and photo control points were established with steel rods. Locations of the existing monuments and the photo control points are shown in Figure 6. Positions and elevations of the monuments and photo control points are listed in the following tabulation:

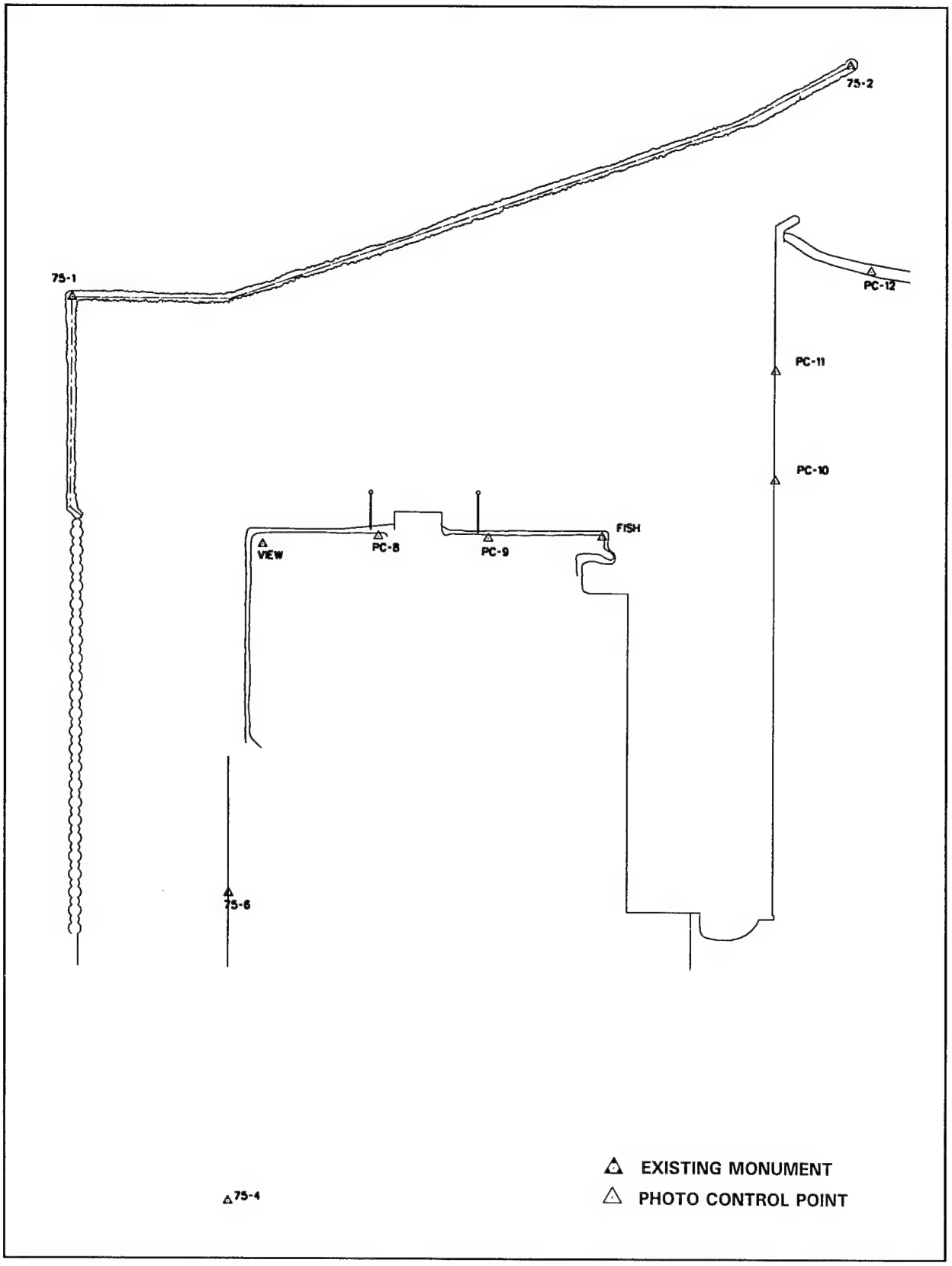


Figure 6. Locations of existing monuments and photo control points

Identification Number	Northing	Easting	El, m (ft)
Existing Monuments			
75-1	2,330,109.680	2,931,266.441	+3.99 (+13.1)
75-2	2,331,423.670	2,935,655.891	+3.84 (+12.59)
FISH	2,328,786.443	2,934,270.221	+3.64 (+11.93)
75-4	2,325,048.094	2,932,163.567	+3.90 (+12.78)
VIEW	2,328,735.682	2,932,345.500	+3.76 (+12.33)
75-6	2,326,776.614	2,932,162.882	+3.92 (+12.86)
Photo Control Points			
PC-8	2,328,784.640	2,933,000.581	+3.11 (+10.2)
PC-9	2,328,776.998	2,933,625.206	+3.41 (+11.2)
PC-10	2,329,111.759	2,935,244.342	+4.22 (+13.85)
PC-11	2,329,723.315	2,935,244.909	+4.27 (+14.00)
PC-12	2,330,280.904	2,935,779.315	+5.05 (+16.58)

Horizontal positions are based on the Indiana State Plane Coordinate System, and all elevations are referenced to lwd.

Aerial Photography

Aerial photography is a very effective means of capturing images of large areas for later analysis, study, visual comparison to previous or subsequent photography, or measurement and mapping. Its chief attribute is the ability to freeze a moment in time, while capturing extensive detail.

Aerial photography was obtained along the breakwater with a Zeiss RMKA 15/23 aerial mapping camera (228-mm by 228-mm (9-in. by 9-in.) format). Color photos were secured from a fixed-wing aircraft flying at an altitude of 549 m (1,800 ft), which resulted in high-resolution images and contact prints with scales of 1:3,600. Photographic stereo pairs were obtained during the flights. Stereo pairs secured for the breakwater are shown in Figure 7. The aerial photography was obtained on 10 November 1994. The lake level during the photography was +0.7 m (+2.3 ft) lwd.

a. Easternmost photo image

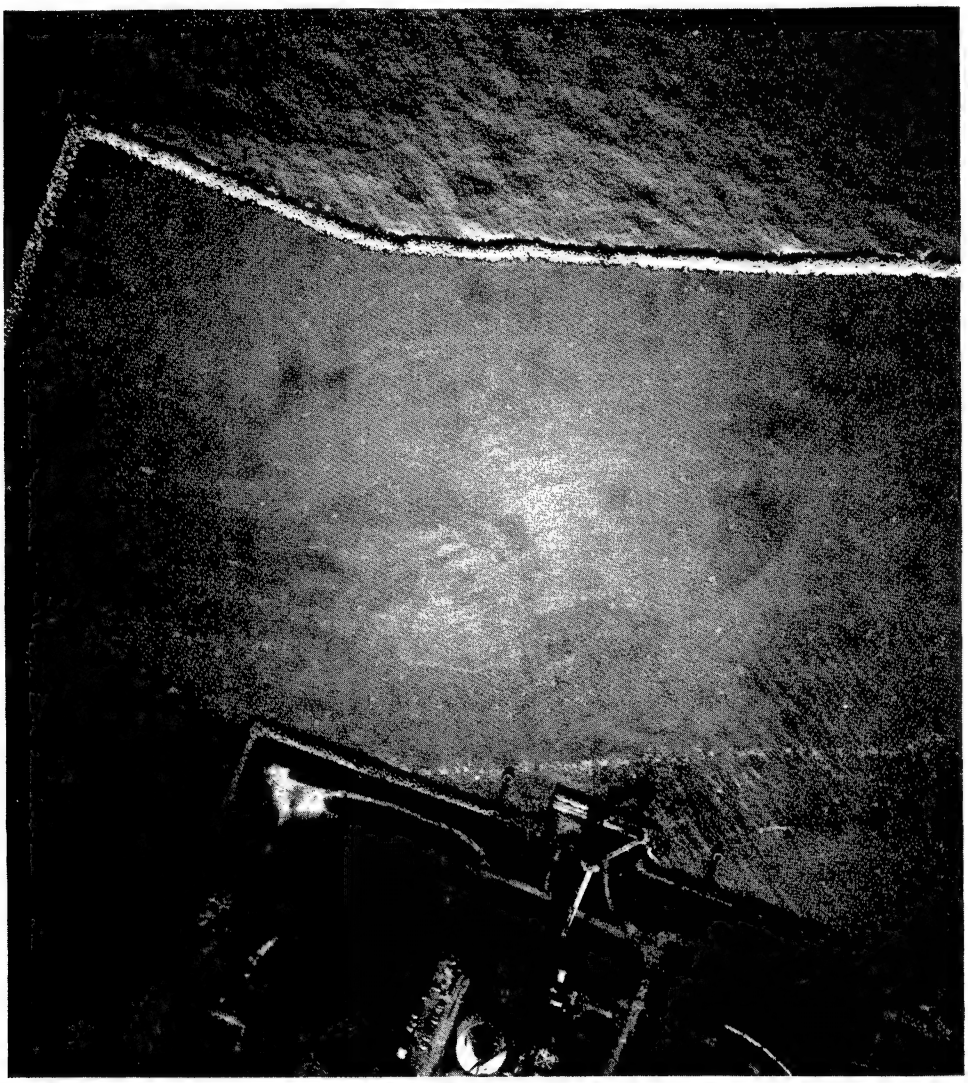
Figure 7. Stereo pair photographs for Burns Harbor North Breakwater (Sheet 1 of 5)

b. Eastern photo image

Figure 7. (Sheet 2 of 5)

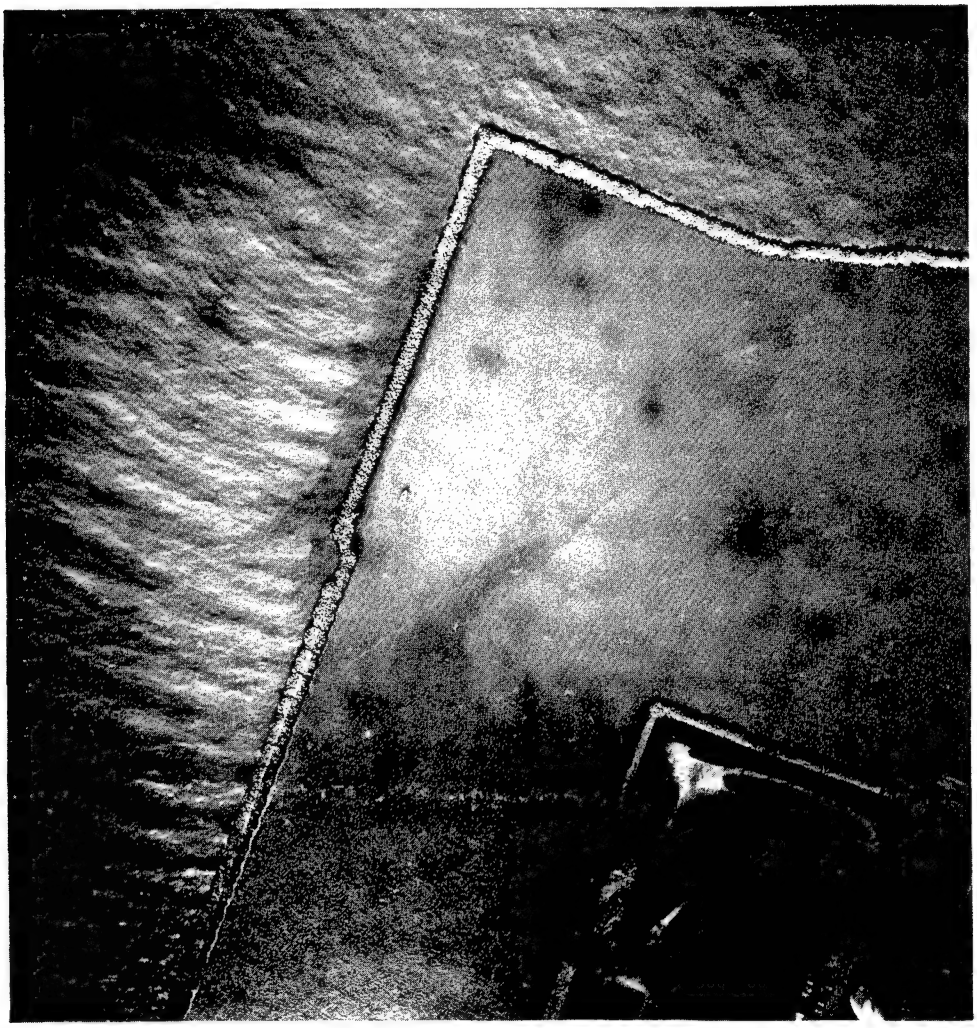
c. Middle photo image

Figure 7. (Sheet 3 of 5)



d. Western photo image

Figure 7. (Sheet 4 of 5)



e. Westernmost photo image

Figure 7. (Sheet 5 of 5)

Photogrammetric Analysis of Armor Units

When aerial photography is planned and conducted so that each photo image overlaps the next by 60 percent or more, the two photographs comprising the overlap area can be positioned under an instrument called a stereoscope and viewed in extremely sharp three-dimensional detail. If properly selected survey points on the ground have previously been targeted and are visible in the overlapping photography, very accurate measurements of any point appearing in the photographs can be obtained. This technique is called photogrammetry.

The stereo pair images obtained during aerial photography at Burns Harbor were viewed in a Galileo Digicart Model 40 Analytical Stereoplotter, and stereomodels were oriented to the monument data previously obtained. In the stereomodel, very accurate horizontal and vertical measurements can be made of any point on any armor unit appearing in the print. The accuracy of photogrammetric spot elevations are on the order of ± 0.06 m (± 0.2 ft). The stereomodel was used for all photogrammetric compilation and development of orthophotography.

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. The digital orthophoto is created by scanning an aerial photograph with a precision image scanner. The scanned data file is digitally rectified to an orthographic projection by processing each image pixel. Orthophotos were prepared for the entire 1,414-m- (4,640-ft-) long North Breakwater. Precise horizontal measurements may be obtained from the orthophotos using an engineer scale since the image has been rectified and is free from skewness and distortion. An example of an orthophoto is shown in Figure 8.

In addition to digital orthophotos, point plot maps, contour maps, and cross sections were developed for the North Breakwater using a digital terrain model (DTM). Point plot maps consisted of an approximately 0.3-m (1-ft) grid pattern overlaid on the structure. Precise vertical and horizontal measurements were obtained at the intersections of the grid. An example of a point plot map showing elevations on the breakwater is shown in Figure 9. Areas where no elevations are shown are shadowed areas, or voids between the armor units. Contour maps of the breakwater, developed from the DTM, for a 0.3-m (1-ft) contour interval are shown in Appendix A. In addition, using the analytical stereoplotter and DTM grid, cross sections of the breakwater were developed along the trunk of the breakwater at 15.2-m (50-ft) intervals and around the head of the structure at 0.26-rad (15-deg) intervals as shown in Figure 10. These cross sections are presented in Appendix B.

An examination of the breakwater topography and cross-section data (Appendixes A and B) reveals low areas along much of the breakwater. Cumulatively, about 344 linear m (1,130 linear ft), or 24 percent of the total length, of the breakwater is below the design crest el of +4.3 (+14).

Figure 8. Orthophoto for a portion of the North Breakwater

Figure 9. Point plot map for a portion of the North Breakwater

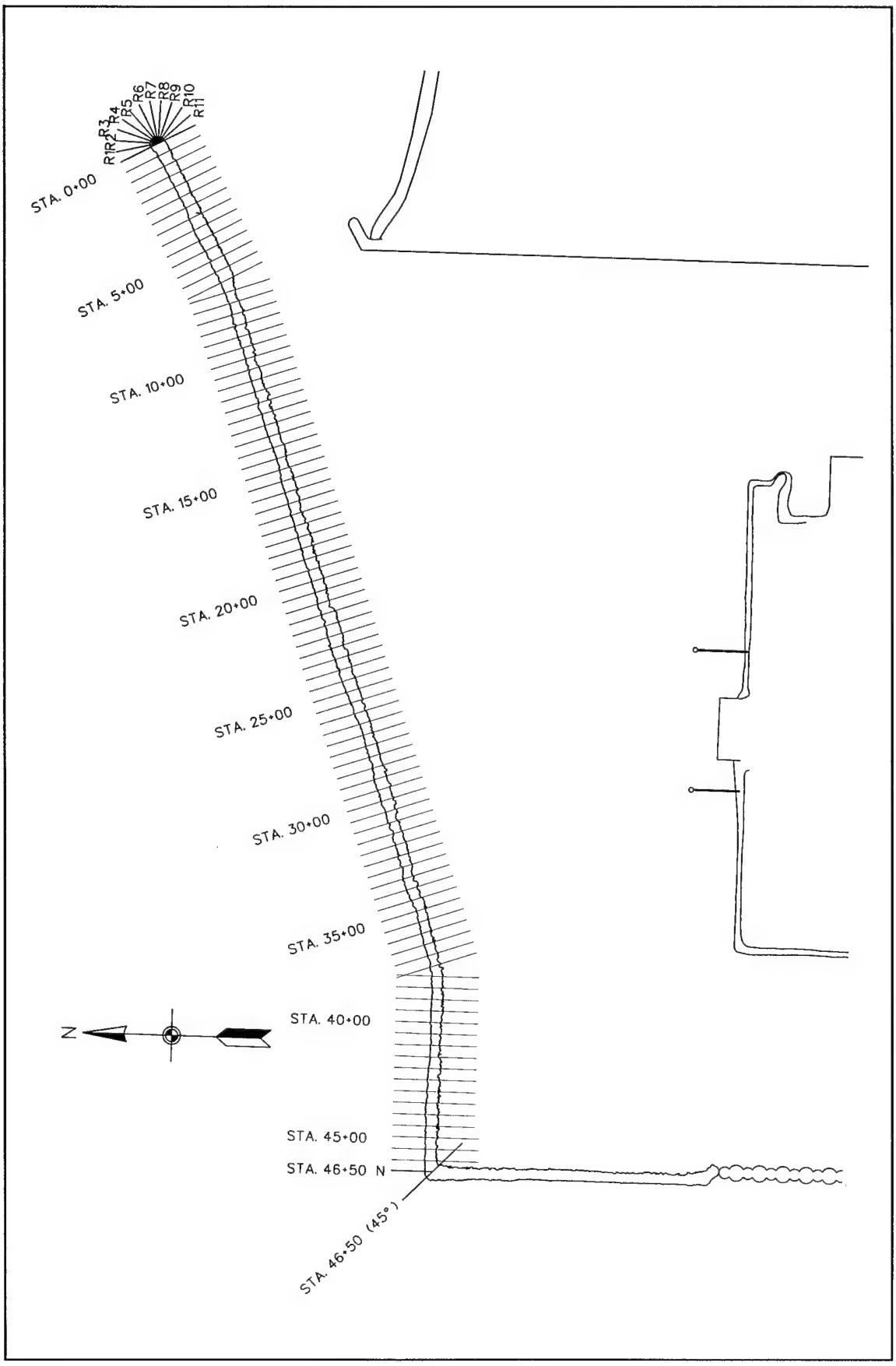


Figure 10. Locations of cross sections developed along the trunk and head of the North Breakwater

Most of these low areas range in elevation from +3.7 to +4.3 (+12 to +14). Only about 66 linear m (215 linear ft) cumulative length of the breakwater (4.6 percent) is below the +3.7-m (+10-ft) elevation. Low areas in the structure appear to be concentrated between sta 12+20-15+00 and sta 30+80-37+50. These data also reveal that the design crest width of 5.2 m (17 ft) is not maintained in many areas. In addition, on some portions of the structure, the slope on the harbor side of the breakwater is steeper than the original 1V:1.5H design.

Data provided in Appendixes A and B include the above-water portion of the breakwater developed during the photogrammetric analysis. These data will be used for comparisons in subsequent surveys under the Periodic Inspections Work Unit. As stated earlier, the Chicago District funded work that also included underwater surveys of the breakwater and merging of the subsurface and surface data to develop cross sections of the entire structure. An example of one of the merged cross sections is shown in Figure 11.

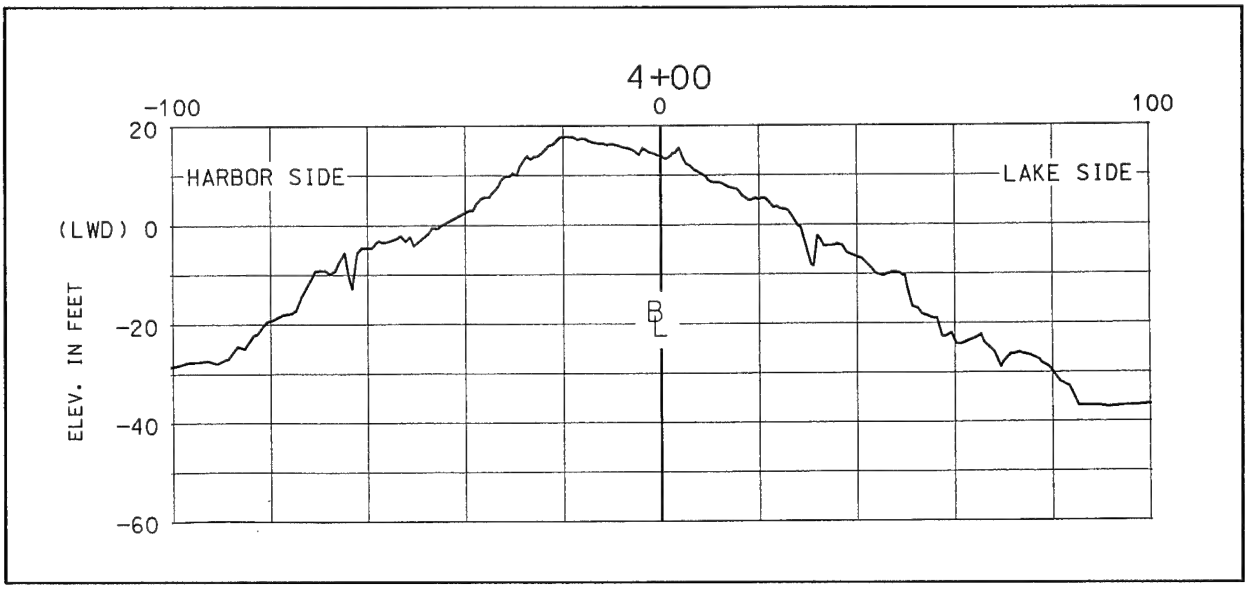


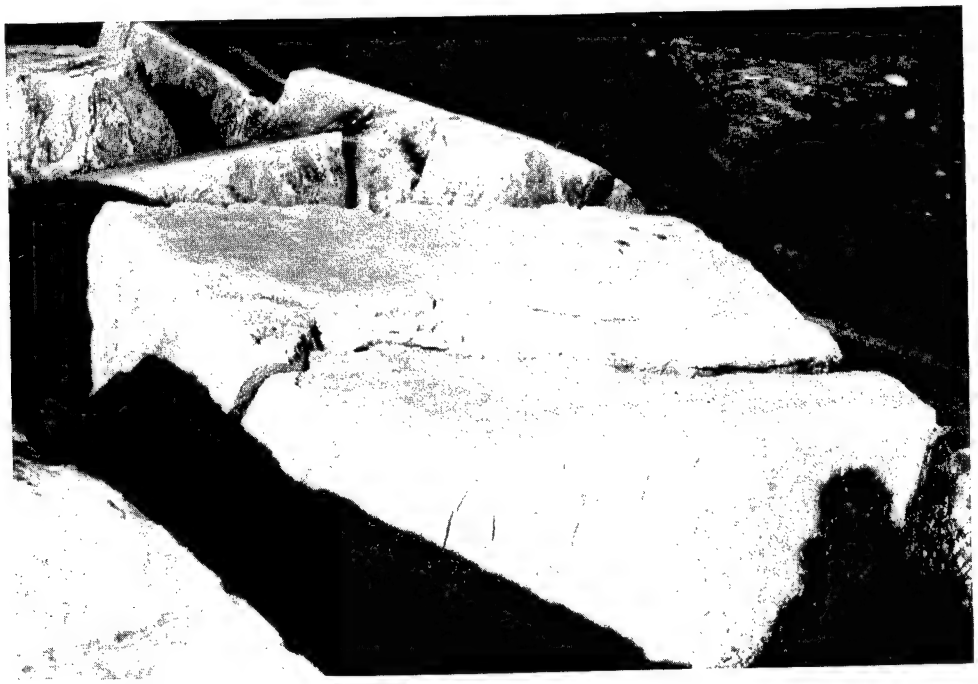
Figure 11. Example of breakwater cross section after merging surface and subsurface surveys

Full-scale hard copies of aerial photographs, point plot maps, contour maps, cross sections, and orthophotos are on file by the authors. In addition, all photogrammetric compilations and analyses and map data have been stored on diskettes in InterGraph files for future use. In summary, very detailed and accurate information relative to the armor unit positions for the Burns Harbor North Breakwater have been captured by aerial photography and photogrammetric analysis. Data are stored on diskettes and can be retrieved and compared against data obtained during subsequent monitoring. Thus, armor unit movement data may continue to be quantified precisely in future years.

Broken Armor Stone Survey

During the period 25-26 July 1995, a survey of broken/cracked armor stone above the waterline on the 1,414-m- (4,640-ft-) long Burns Harbor North Breakwater was conducted. During the inspection, each broken armor stone was identified and photographed, and its approximate location relative to breakwater station and distance from a baseline was recorded. The baseline was the approximate center line of the structure. Armor stones with hairline cracks were not counted, only those that were cracked all the way through. Views of representative types of breaks are shown in Figure 12. The water was relatively clear during the survey, and the lake level was +0.6 m (+2.0 ft) lwd. The data recorded during the broken armor stone inventory are listed in Table 1.

The survey revealed a total of 165 broken or cracked armor stones above the waterline. Of the 165 stones, 26 were located along the breakwater crest, 95 on the lakeside slope, and 44 on the harbor side slope. No broken armor stones were observed around the head of the structure. The distribution of broken armor stones along the breakwater trunk as a function of station number and offset from the baseline is shown in Figure 13. As shown, broken stones occurred along the entire North Breakwater trunk, but in general, high concentrations were found along the easternmost portion of the structure. About 50 percent of the broken units (82 units) were located on the eastern one third (457 m (1,500 ft)) of the structure. The distribution of broken/cracked armor stones relative to offset from the baseline is shown in Figure 14. The majority of the broken armor stones along the structure (57 percent) were located on the lakeward face of the structure in the active wave zone. About 16 percent of the broken armor units were on the crest of the breakwater and 27 percent were on the harbor side of the structure. Detailed data obtained during the survey will allow for an accurate indication of new breaks when the structure is revisited at some point in the future.



a. Station 0+00

b. Station 11+78

Figure 12. View of broken armor stone on North Breakwater (Continued)

c. Station 22+89

d. Station 44+65

Figure 12. (Concluded)

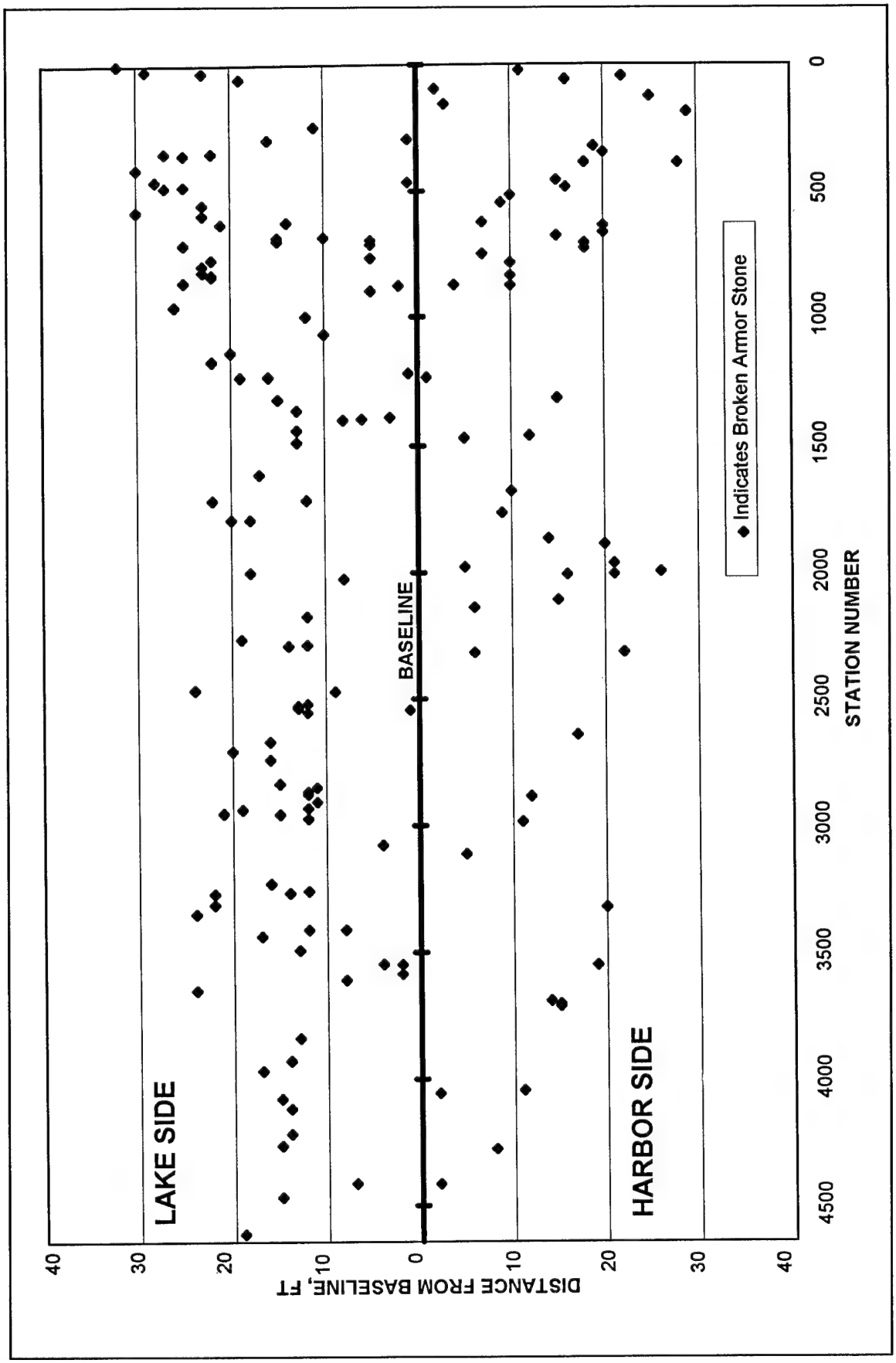


Figure 13. Distribution of broken armor stones along trunk relative to station number

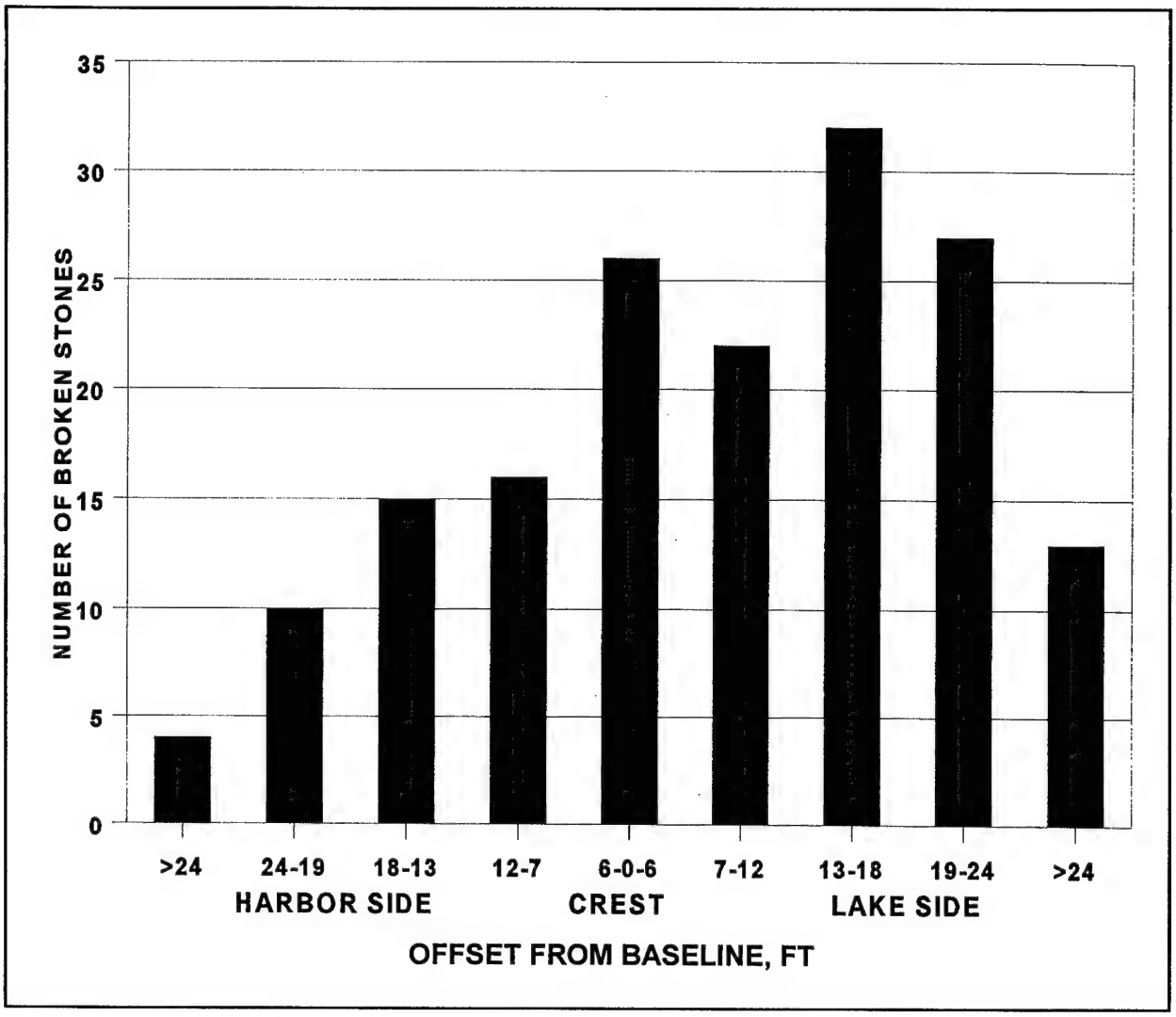


Figure 14. Distribution of broken armor stones relative to distance from baseline

3 Summary

Since construction of the Burns Harbor North Breakwater, extensive breakwater damage has occurred. Maintenance of the crest elevation and structure cross section required an average of about 693,100 kg (7,640 tons) of stone per year in the first 19 years of operation. The monitoring effort for Burns Harbor during the period 1985-1989, however, included little sound, quantifiable data relative to the positions of armor stones on the North Breakwater.

Under the current Periodic Inspections Work Unit of the Monitoring Completed Coastal Projects Program, data from limited ground-based surveys, aerial photography, and photogrammetric analysis have been obtained to establish very precise base level conditions for the Burns Harbor North Breakwater. Accuracy of the photogrammetric analysis was validated and defined through comparison of ground and aerial survey data on monuments established on the structure. A method of high-resolution stereo aerial photographs, a stereoplotter, and Intergraph-based software has been developed to analyze the entire above-water armor unit fields and quantify armor positions and subsequent movement. A detailed broken armor unit survey conducted during the current effort has resulted in a well-documented data set that can be compared with subsequent survey data.

Now that base (control) conditions have been defined at a point in time and methodology has been developed to closely compare subsequent years of high-resolution data for the Burns Harbor North Breakwater, the site will be revisited in the future under the Periodic Inspections Work Unit to gather data with which assessments can be made on the long-term response of the structure to its environment. The insight gathered from these efforts will allow engineering decisions to be made, based on sound data, as to whether or not closer surveillance and/or repair of the structure might be required to reduce its chances of failing catastrophically. The periodic inspection methods developed and validated for these structures may be used to gain insight into other U.S. Army Corps of Engineers structures.

References

Acuff, H. F., and Bottin, R. R., Jr. (1995). "Reef breakwater design for Burns Waterway Harbor, Indiana," Technical Report CERC-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, R. R., Jr. (1988). "Case histories of Corps breakwater and jetty structures; Report 3, North Central Division," Technical Report REMR-CO-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Carver, R. D., and Wright, B. J. (1995). "Reef breakwater wave-attenuation and stability tests, Burns Waterway Harbor, Indiana," Technical Report CERC-95-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Carver, R. D., Dubose, W. G., and Wright, B. J. (1993). "Rubble-mound breakwater wave attenuation and stability tests, Burns Waterway Harbor, Indiana," Technical Report CERC-93-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

McGehee, D. M. and Moritz, H. P. "Burns Harbor, Indiana, Monitoring Study; Overview of approach and results," (in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Engineer District, Chicago. (1994). "Burns Waterway Harbor, Indiana, Breakwater major rehabitation," Design Memorandum, Chicago, IL.

Table 1
Broken Armor Stone Inventory

Stone No.	Station	Distance from Baseline m (ft)		Stone No.	Station	Distance from Baseline m (ft)	
		Lake Side	Harbor Side			Lake Side	Harbor Side
1	0+00	9.8 (32)		2	0+22	8.8 (29)	
3	0+23		3.4 (11)	4	0+29	7.0 (23)	
5	0+47		6.7 (22)	6	0+55	5.8 (19)	
7	0+60		4.9 (16)	8	0+94		0.6 (2)
9	1+26		7.6 (25)	10	1+53		0.9 (3)
11	1+87		8.8 (29)	12	2+47	3.4 (11)	
13	2+92	0.3 (1)		14	2+98	4.9 (16	
15	3+22		5.8 (19)	16	3+47		6.1 (20)
17	3+53	8.2 (27)		18	3+53	6.7 (22)	
19	3+59	7.6 (25)		20	3+88		5.5 (18)
21	3+90		8.5 (28)	22	4+18	9.1 (30)	
23	4+58		4.6 (15)	24	4+65	8.5 (28)	
25	4+65	0.3 (1)		26	4+85	7.6 (25)	
27	4+85		4.9 (16)	28	4+90	8.2 (27)	
29	5+18		3.0 (10)	30	5+46		2.7 (9)
31	5+59	7.0 (23)		32	5+60	7.0 (23)	
33	5+86	9.1 (30)		34	5+88	9.1 (30)	
35	6+01	7.0 (23)		36	6+24		2.1 (7)
37	6+28	4.3 (14)		38	6+35	6.4 (21)	
39	6+40		6.1 (20)	40	6+68		6.1 (20)
41	6+80		4.6 (15)	42	6+88	3.0 (10)	
43	6+90	4.6 (15)		44	6+99	1.5 (5)	
45	7+03	4.6 (15)		46	7+10		5.5 (18)
47	7+16	1.5 (5)		48	7+20	7.6 (25)	
49	7+30		5.5 (18)	50	7+53		2.1 (7)
51	7+69	1.5 (5)		52	7+79	6.7 (22)	

Table 1 (Continued)

Stone No.	Station	Distance from Baseline m (ft)		Stone No.	Station	Distance from Baseline m (ft)	
		Lake Side	Harbor Side			Lake Side	Harbor Side
53	7+88		3.0 (10)	54	8+02	7.0 (23)	
55	8+27	7.0 (23)		56	8+37		3.0 (10)
57	8+38	6.7 (22)		58	8+43	6.7 (22)	
59	8+68	7.6 (25)		60	8+77		3.0 (10)
61	8+78	0.6 (2)		62	8+75		1.2 (4)
63	9+00	1.5 (5)		64	9+63	7.9 (26)	
65	10+00	3.7 (12)		66	10+65	3.0 (10)	
67	11+39	6.1 (20)		68	11+74	6.7 (22)	
69	12+18	0.3 (1)		70	12+32	4.9 (16)	
71	12+32		0.3 (1)	72	12+35	5.8 (19)	
73	13+15		4.6 (15)	74	13+19	4.6 (15)	
75	13+63	4.0 (13)		76	13+89	0.9 (3)	
77	13+95	1.8 (6)		78	14+00	2.4 (8)	
79	14+41	4.0 (13)		80	14+61		3.7 (12)
81	14+70		1.5 (5)	82	14+86	4.0 (13)	
83	16+12	5.2 (17)		84	16+78		3.0 (10)
85	17+12	3.7 (12)		86	17+14	6.7 (22)	
87	17+63		2.7 (9)	88	17+90	6.1 (20)	
89	17+90	5.5 (18)		90	18+65		4.3 (14)
91	18+87		6.1 (20)	92	19+64		6.4 (21)
93	19+78		1.5 (5)	94	19+97		7.9 (26)
95	20+00	5.5 (18)		96	20+06		6.4 (21)
97	20+07		4.9 (16)	98	20+24	2.4 (8)	
99	21+07		4.6 (15)	100	21+38		1.8 (6)
101	21+72	3.7 (12)		102	22+64	5.8 (19)	
103	22+85	3.7 (12)		104	22+89	4.3 (14)	

Table 1 (Continued)

Stone No.	Station	Distance from Baseline m (ft)		Stone No.	Station	Distance from Baseline m (ft)	
		Lake Side	Harbor Side			Lake Side	Harbor Side
105	23+15		6.7 (22)	106	23+18		1.8 (6)
107	24+65	7.3 (24)		108	24+72	2.7 (9)	
109	25+22	3.7 (12)		110	25+29	4.0 (13)	
111	25+37	4.0 (13)		112	25+46	0.3 (1)	
113	25+55	3.7 (12)		114	26+45		5.2 (17)
115	26+71	4.9 (16)		116	27+08	6.1 (20)	
117	27.42	4.9 (16)		118	28+52	3.4 (11)	
119	28+36	4.6 (15)		120	28+68	3.7 (12)	
121	28+77	3.7 (12)		122	28+86		3.7 (12)
123	29+07	3.4 (11)		124	29+31	3.7 (12)	
125	29+37	5.8 (19)		126	29+52	6.4 (21)	
127	29+54	4.6 (15)		128	29+71	3.7 (12)	
129	29+84		3.4 (11)	130	30+75	1.2 (4)	
131	31+10		1.5 (5)	132	32+26	4.9 (16)	
133	32+55	3.7 (12)		134	32+62	4.3 (14)	
135	32+66	6.7 (22)		136	33+09	6.7 (22)	
137	33+21		6.1 (20)	138	33+46	7.3 (24)	
139	34+09	3.7 (12)		140	34+09	2.4 (8)	
141	34+35	5.2 (17)		142	34+90	4.0 (13)	
143	35+46	1.2 (4)		144	35+48	0.6 (2)	
145	35+50		5.8 (19)	146	35+85	0.6 (2)	
147	36+10	2.4 (8)		148	36+50	7.3 (24)	
149	36+92		4.3 (14)	150	37+03		4.6 (15)
151	37+13		4.6 (15)	152	38+40	4.0 (13)	
153	39+29	4.3 (14)		154	39+68	5.2 (17)	

Table 1 (Concluded)

Stone No.	Station	Distance from Baseline m (ft)		Stone No.	Station	Distance from Baseline m (ft)	
		Lake Side	Harbor Side			Lake Side	Harbor Side
155	40+45		3.4 (11)	156	40+56		0.6 (2)
157	40+76	4.6 (15)		158	41+15	4.3 (14)	
159	42+16	4.3 (14)		160	42+62	4.6 (15)	
161	42+77		2.4 (8)	162	44+12	2.1 (7)	
163	44+14		0.6 (2)	164	44+65	4.6 (15)	
165	46+10	5.8 (19)					

Appendix A
Contour Maps of Burns Harbor North Breakwater

This appendix presents contour maps of the Burns Harbor North Breakwater. Topography was developed using the digital terrain model (DTM) as stated in the main text of this report. The breakwater topography is shown on a 0.3-m (1.0-ft) contour interval. Elevations shown are in feet referred to low water datum (lwd). To convert them to meters, multiply by 0.3048. Station numbering on the contour maps is from east to west (right to left). The scale of the maps is 25.4 mm = 3.05 m (1 in = 10 ft).

Figure A1. Topography of Burns Harbor North Breakwater, sta 0+00-0+50

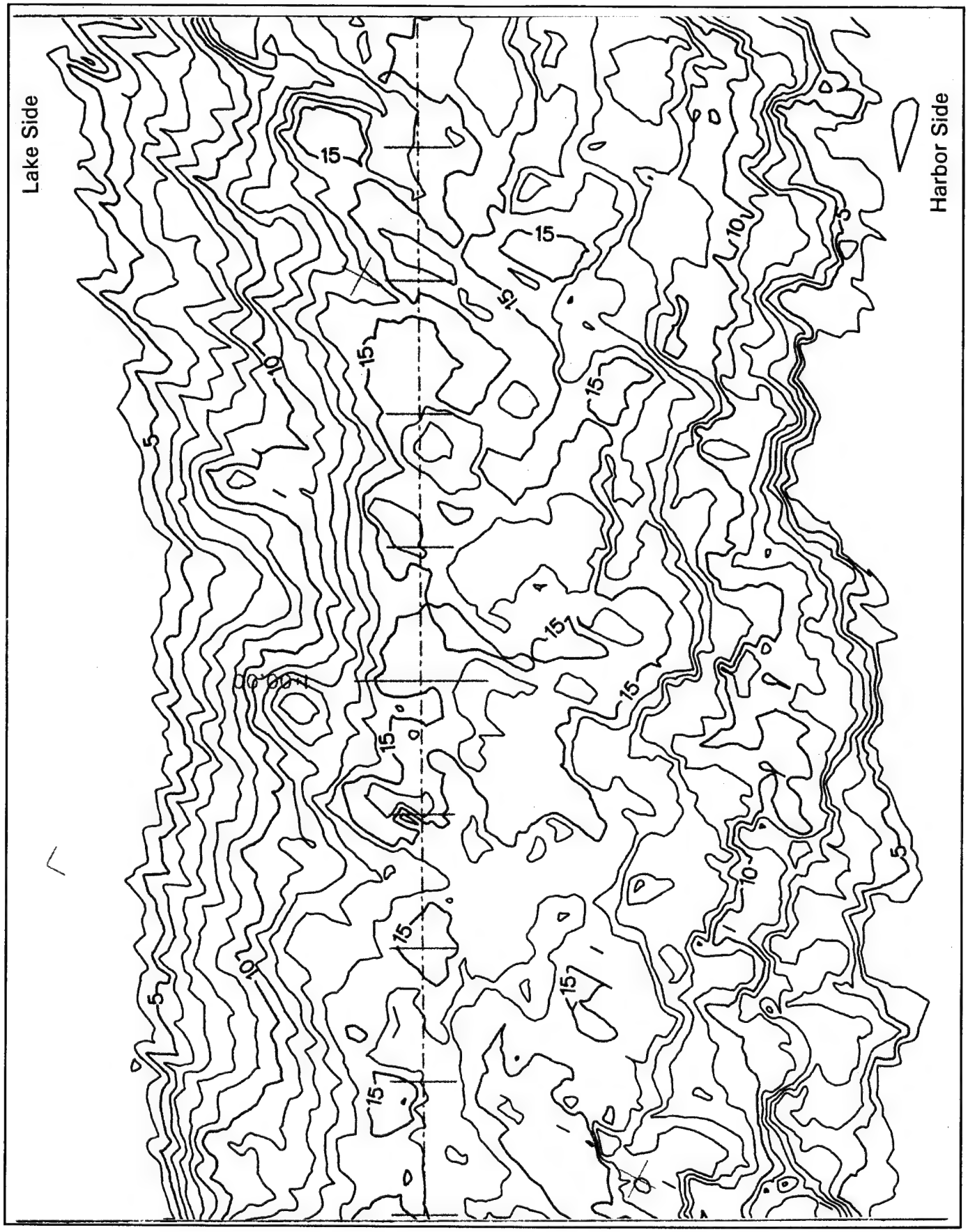


Figure A2. Topography of Burns Harbor North Breakwater, sta 0+50-1+40

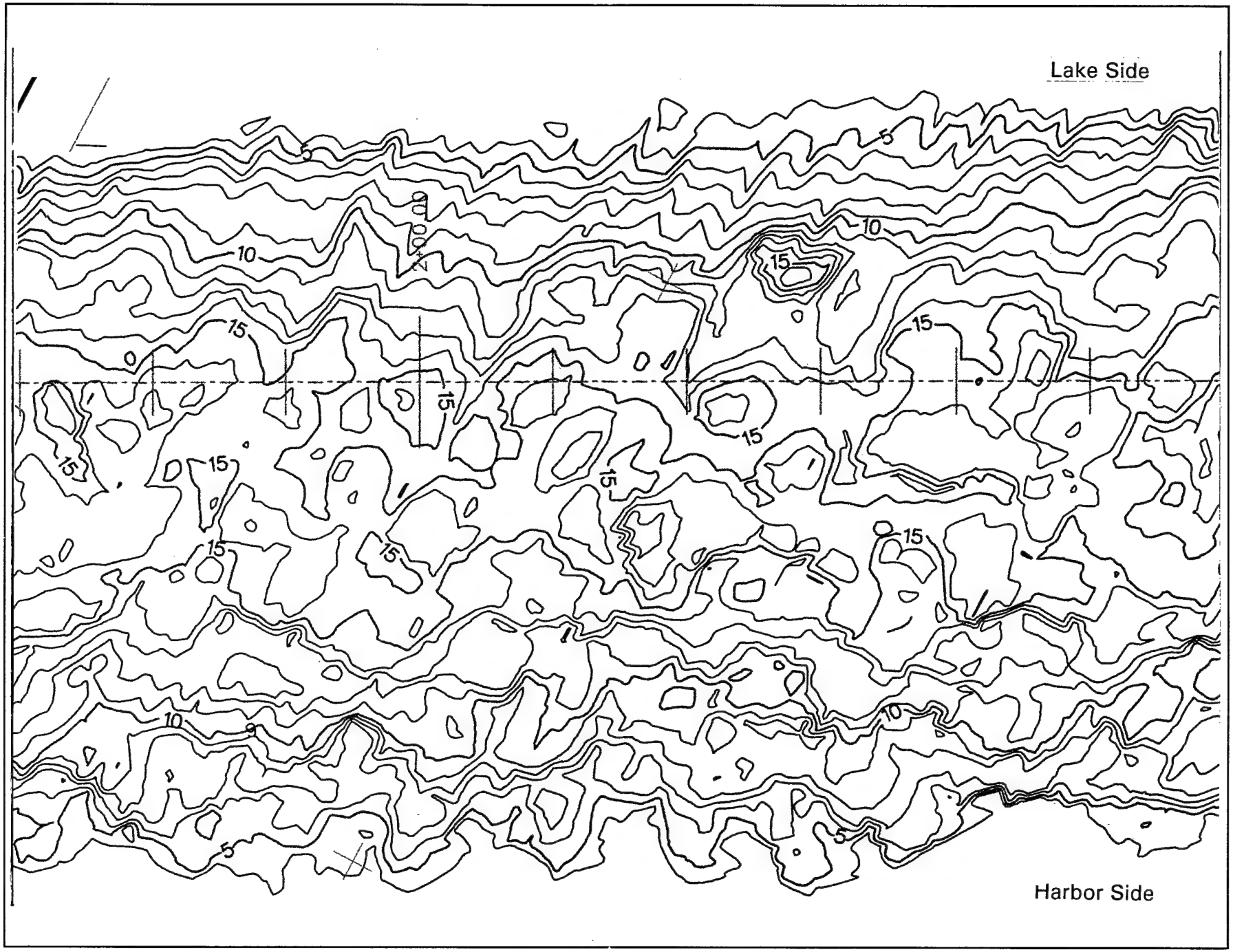


Figure A3. Topography of Burns Harbor North Breakwater, sta 1+40-2+30

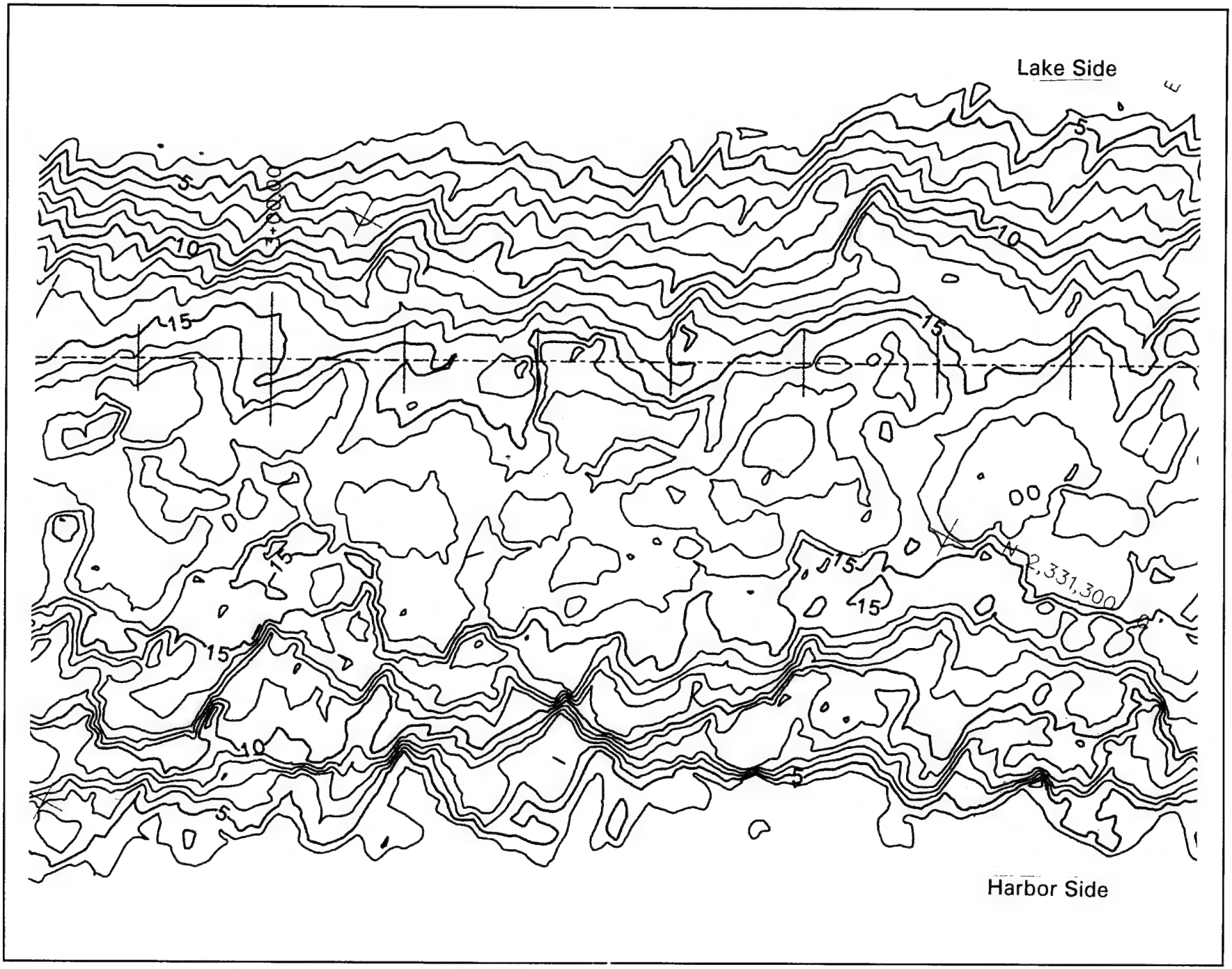


Figure A4. Topography of Burns Harbor North Breakwater, sta 2+30-3+18

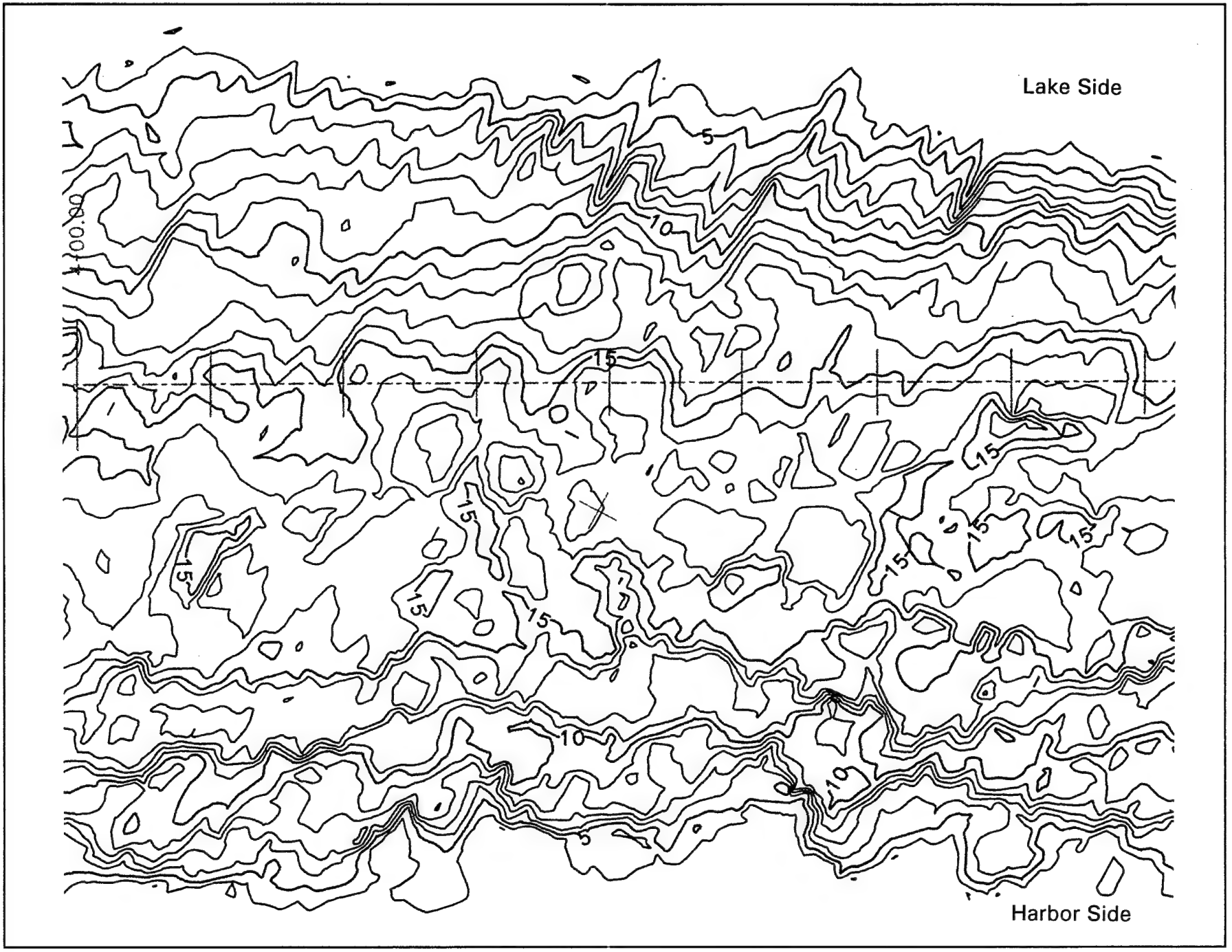


Figure A5. Topography of Burns Harbor North Breakwater, sta 3+18-4+01

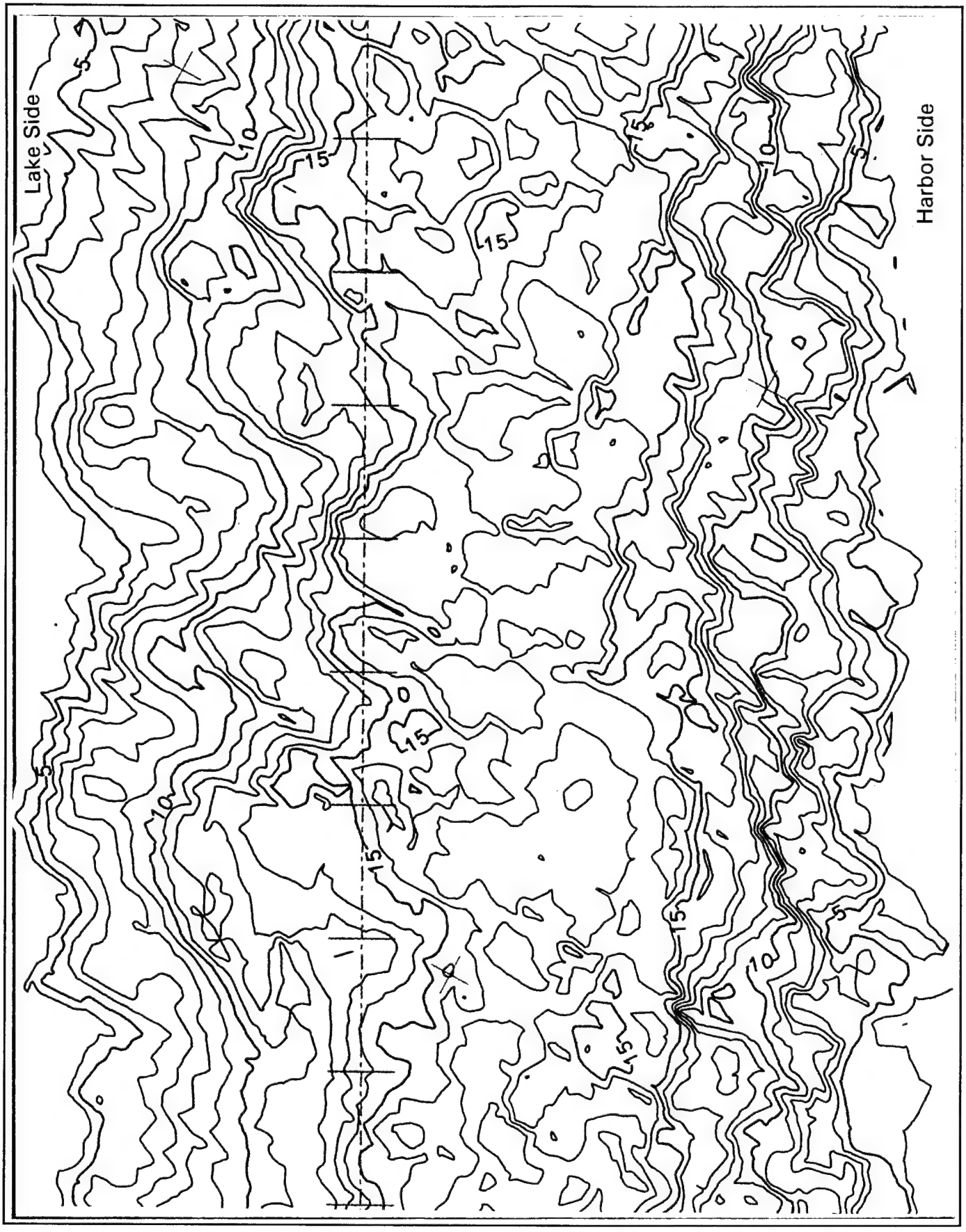


Figure A6. Topography of Burns Harbor North Breakwater, sta 4+01-4+90

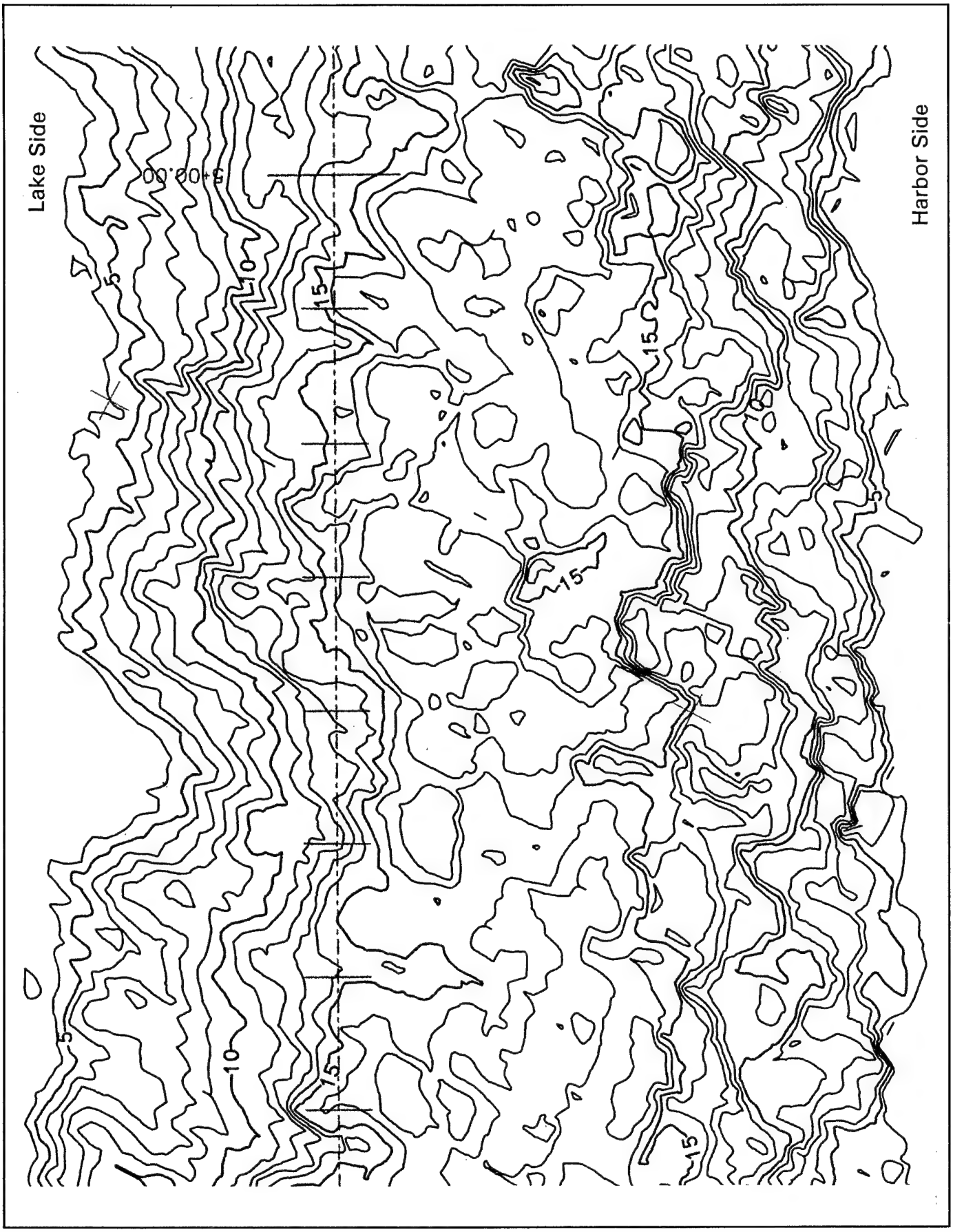


Figure A7. Topography of Burns Harbor North Breakwater, sta 4+90-5+75

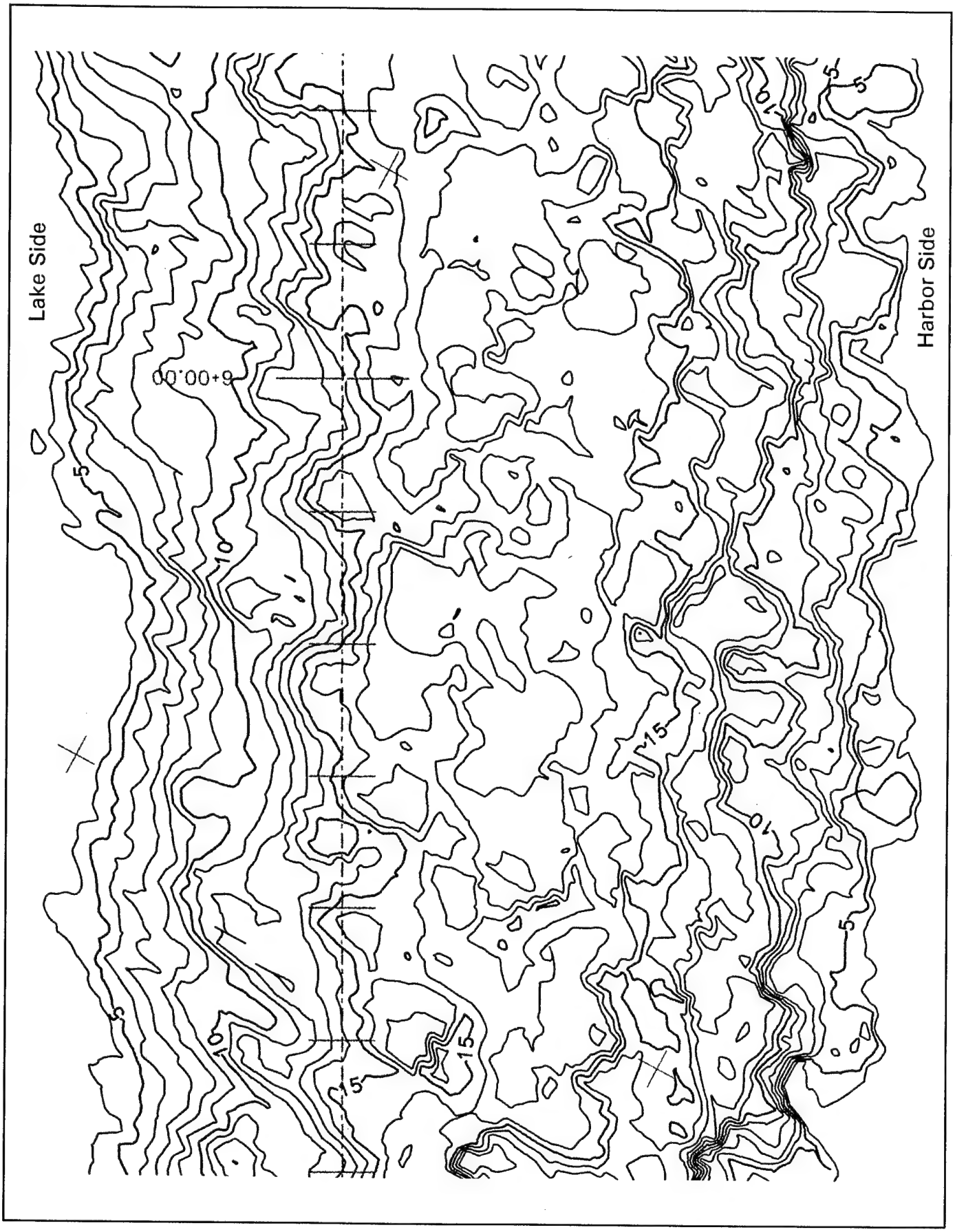


Figure A8. Topography of Burns Harbor North Breakwater, sta 5+75-6+60

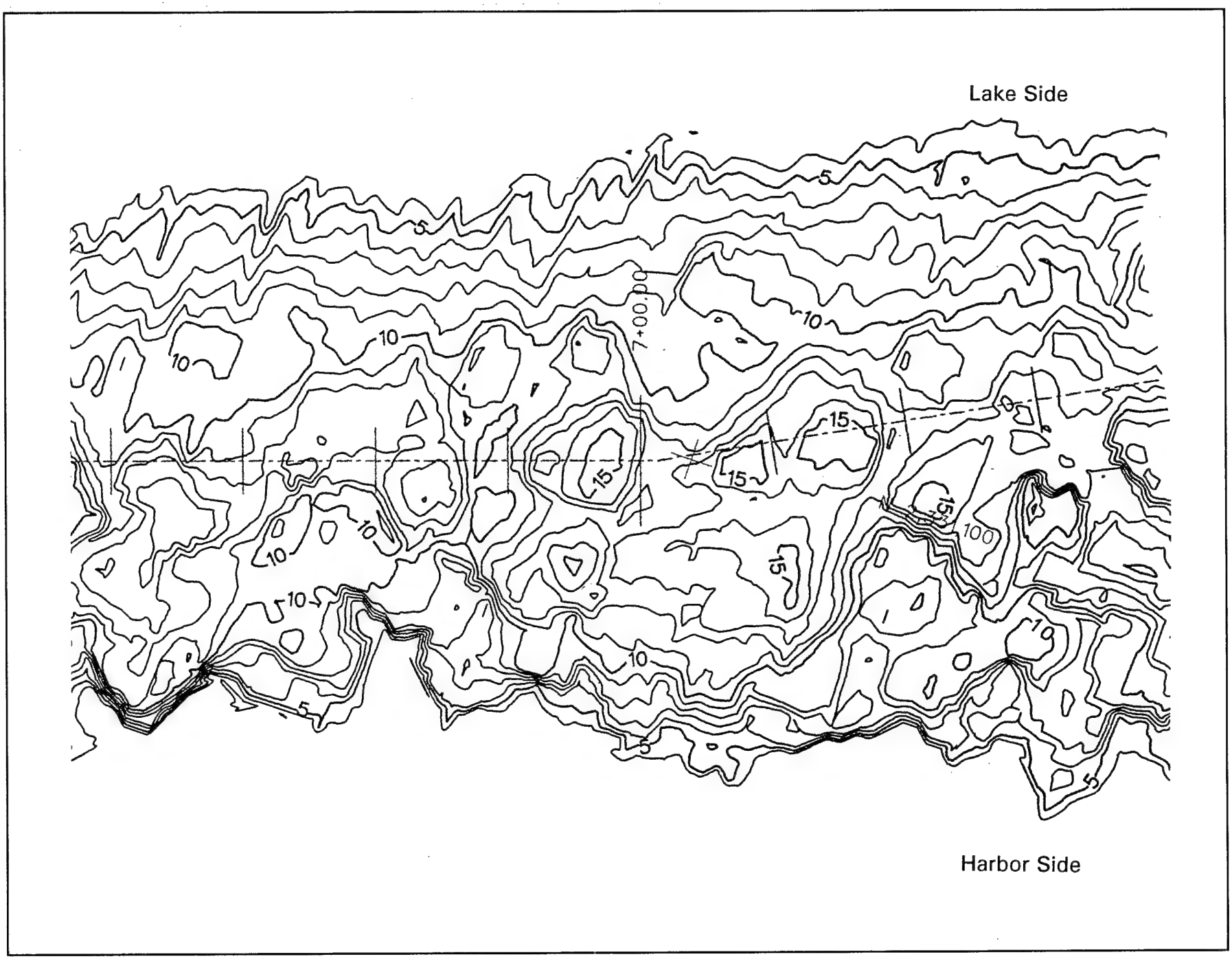


Figure A9. Topography of Burns Harbor North Breakwater, sta 6+60-7+43

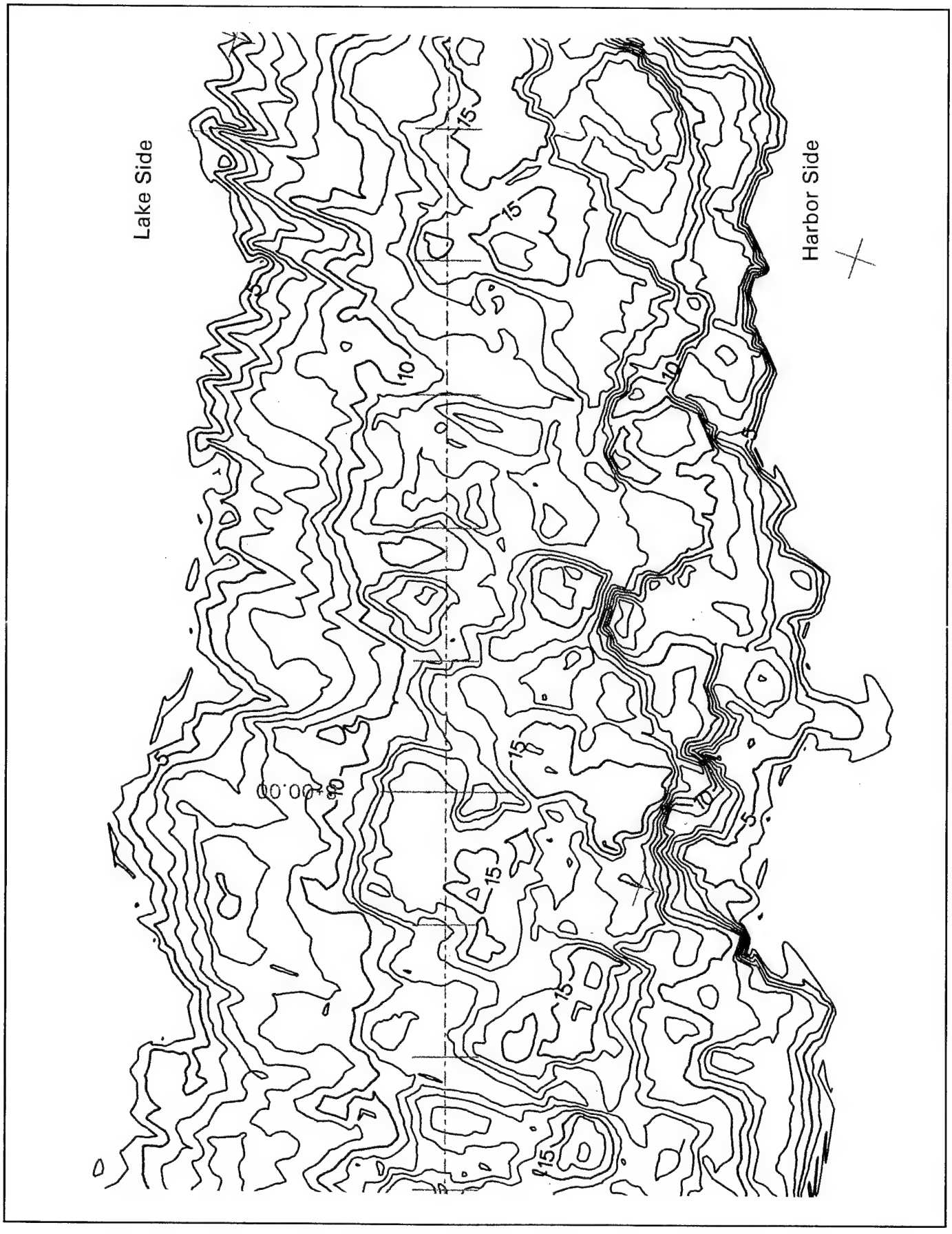


Figure A10. Topography of Burns Harbor North Breakwater, sta 7+43-8+30

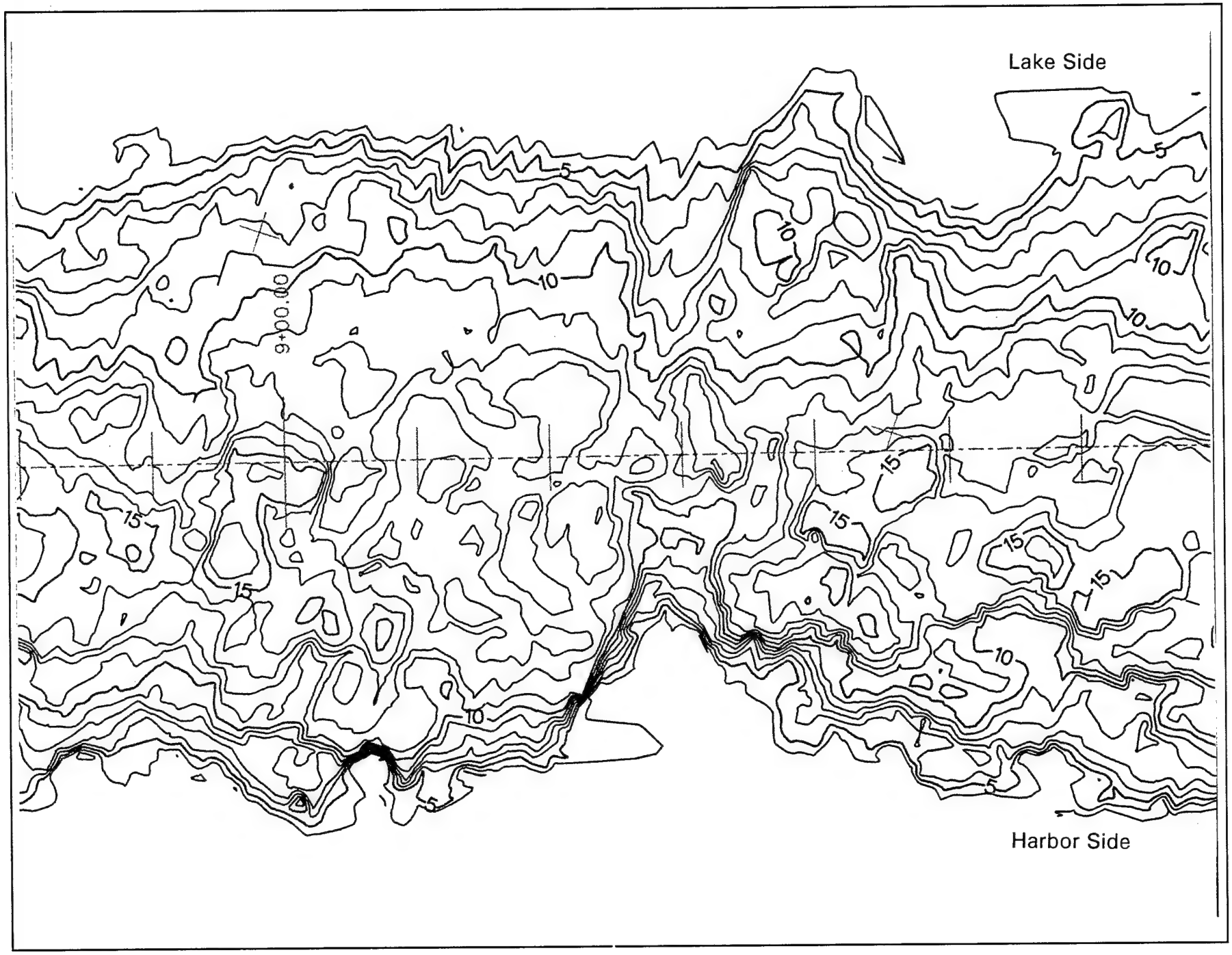


Figure A11. Topography of Burns Harbor North Breakwater, sta 8+30-9+20

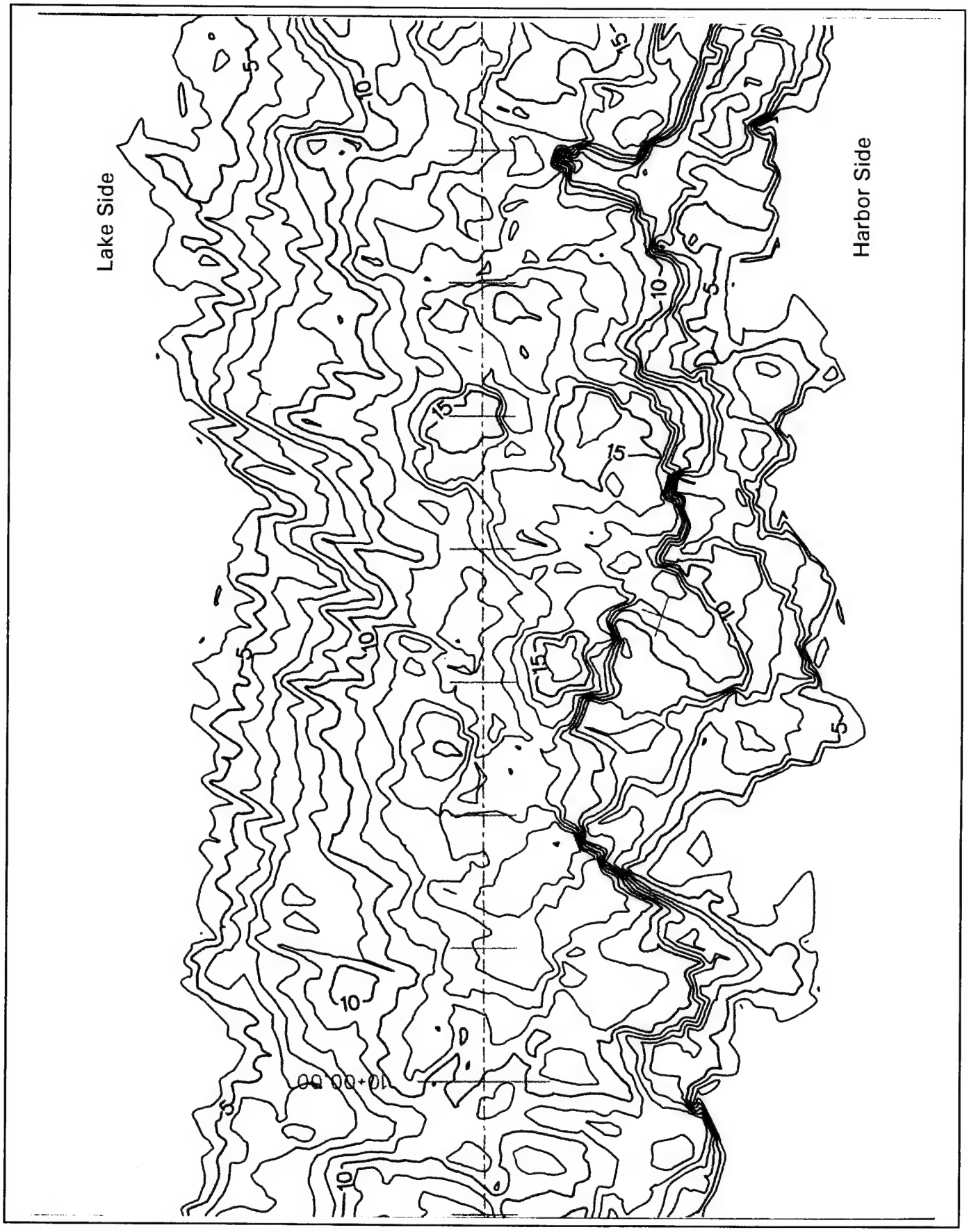


Figure A12. Topography of Burns Harbor North Breakwater, sta 9+20-10+10

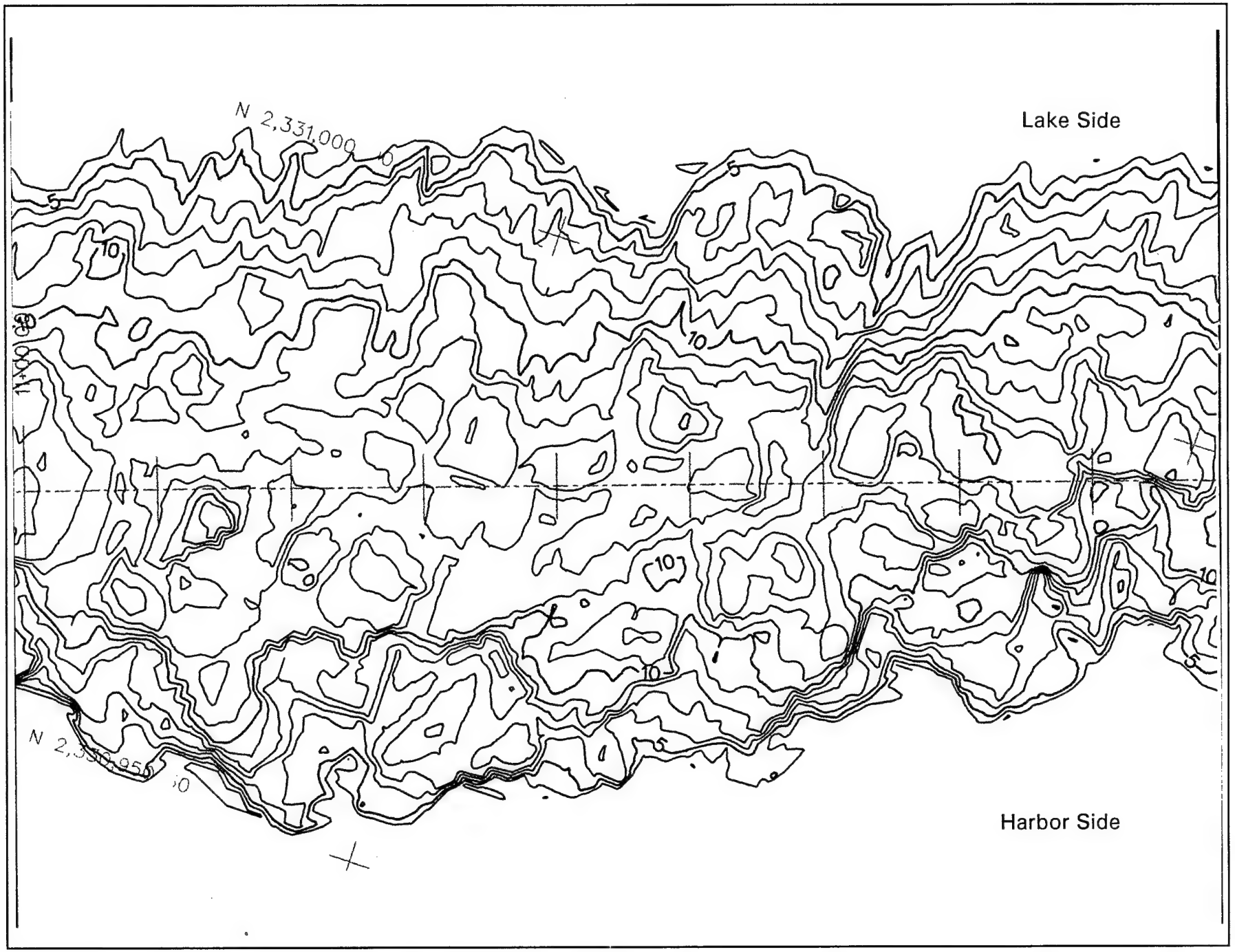


Figure A13. Topography of Burns Harbor North Breakwater, sta 10+10-11+01

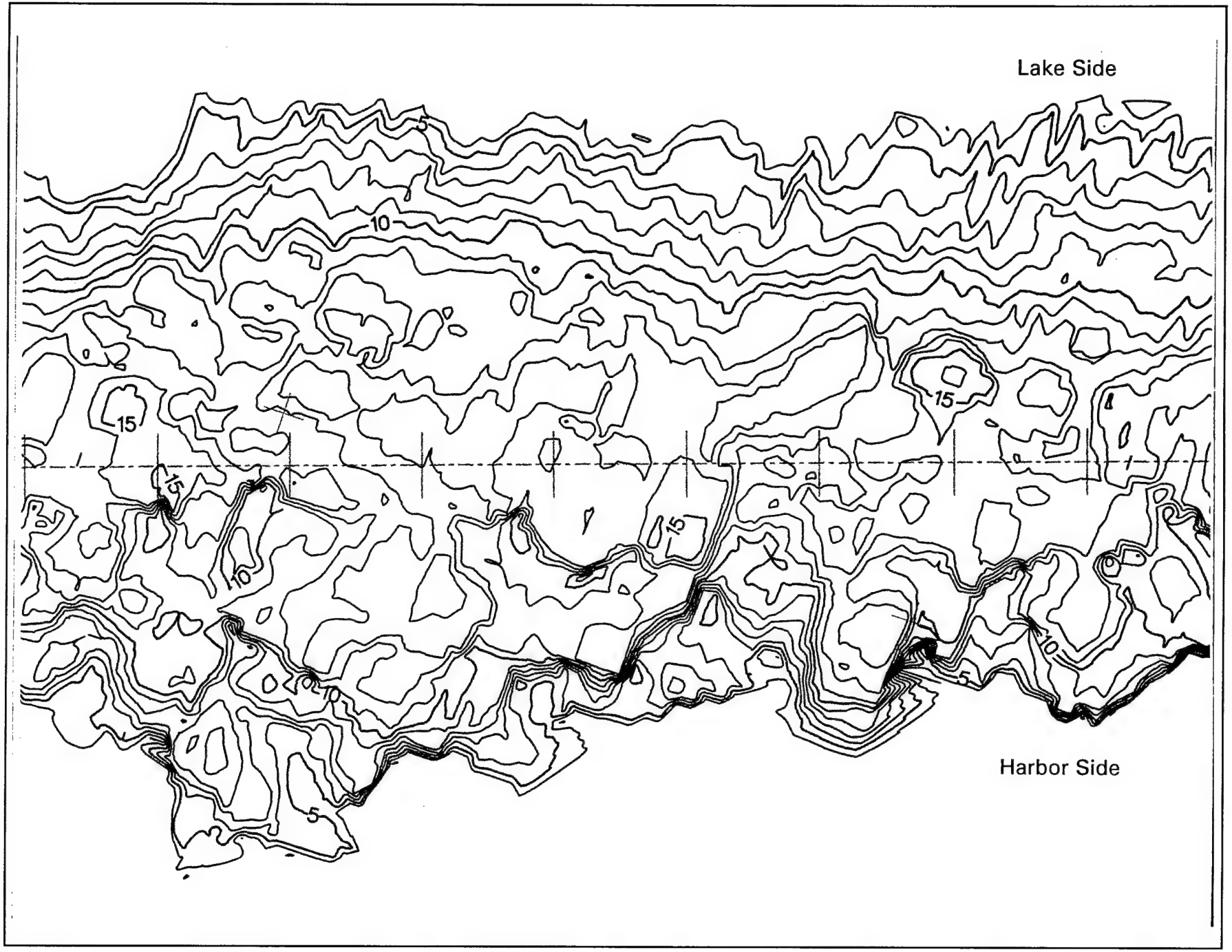


Figure A14. Topography of Burns Harbor North Breakwater, sta 11+01-11+90

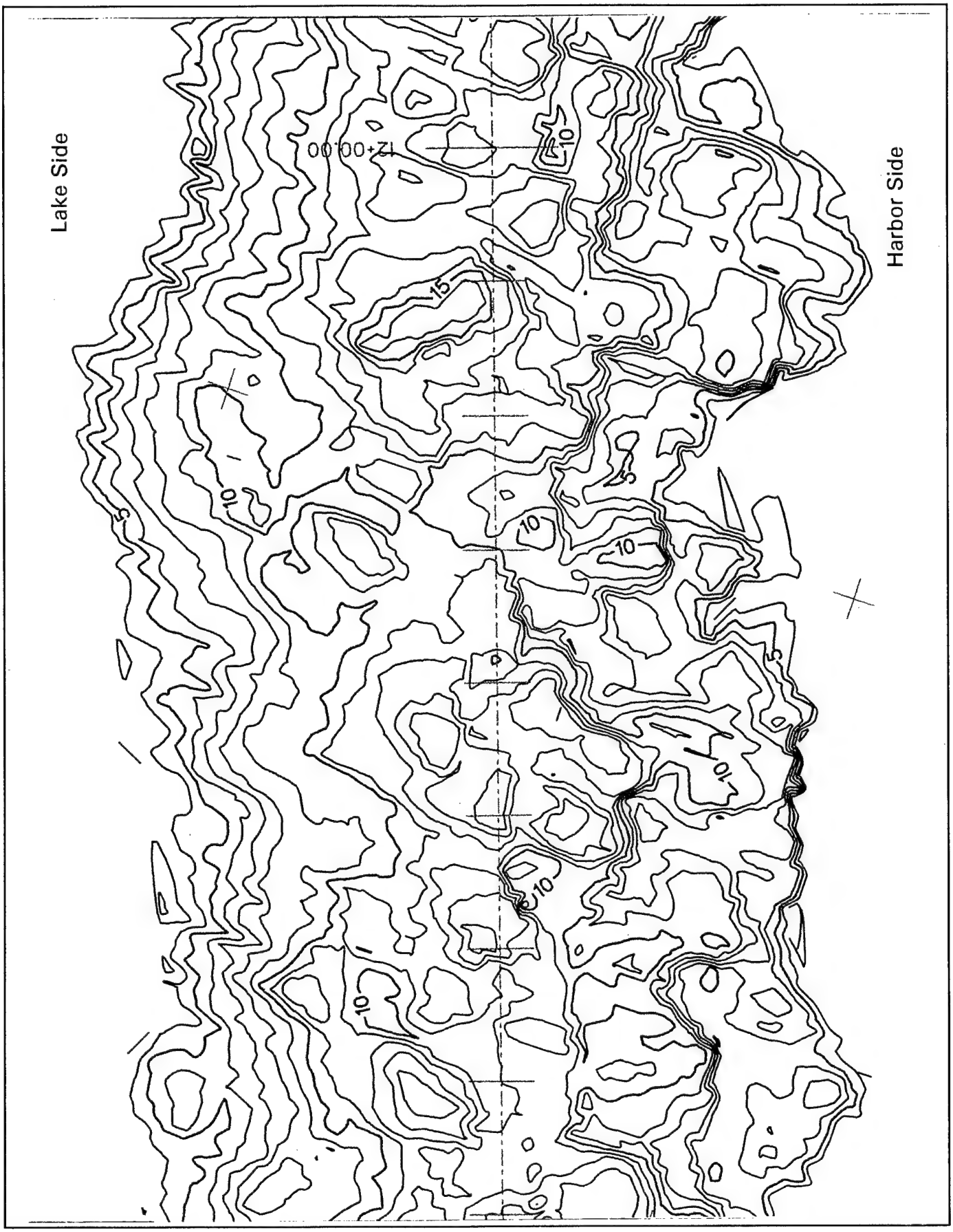


Figure A15. Topography of Burns Harbor North Breakwater, sta 11+90-12+80

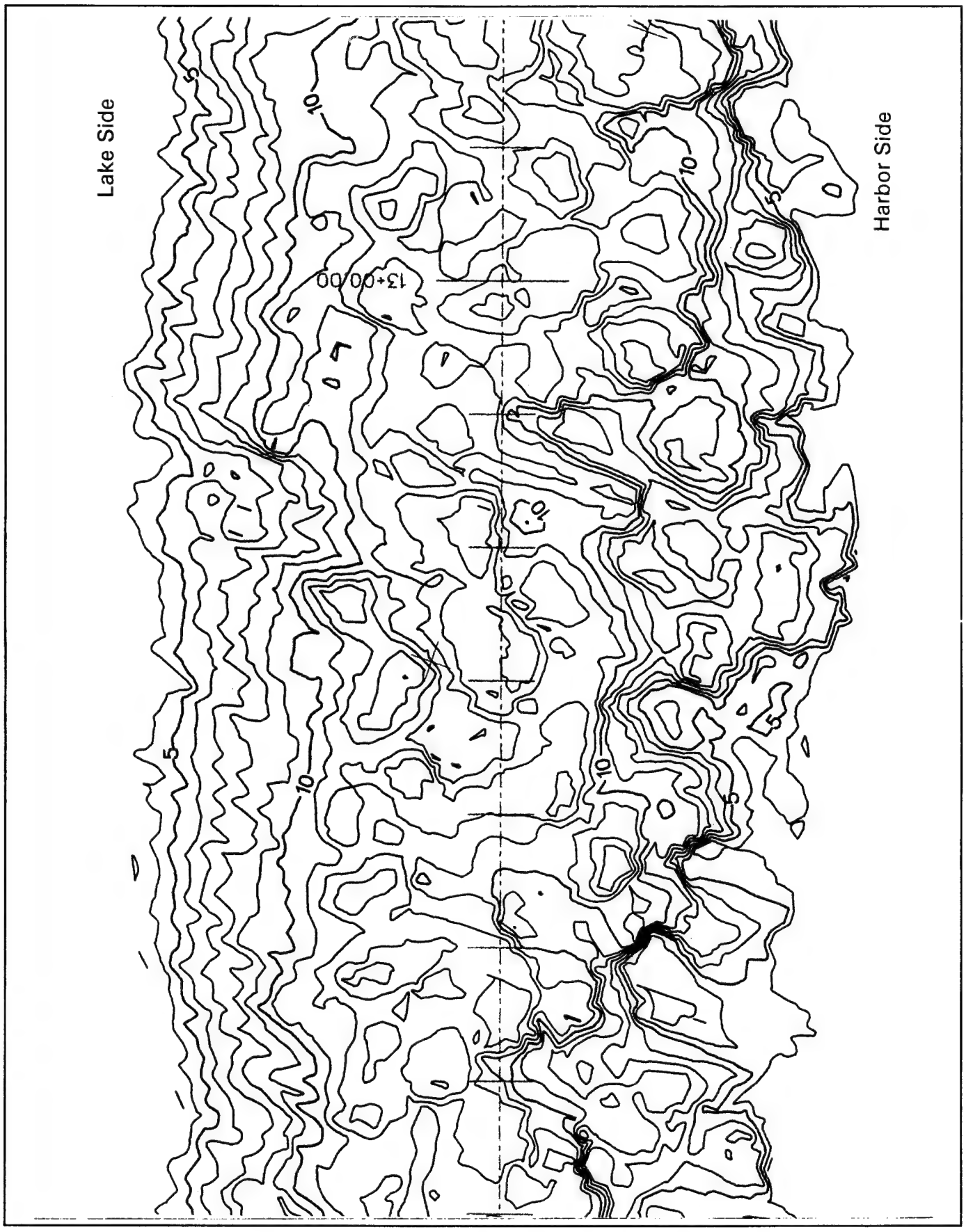


Figure A16. Topography of Burns Harbor North Breakwater, sta 12+80-13+70

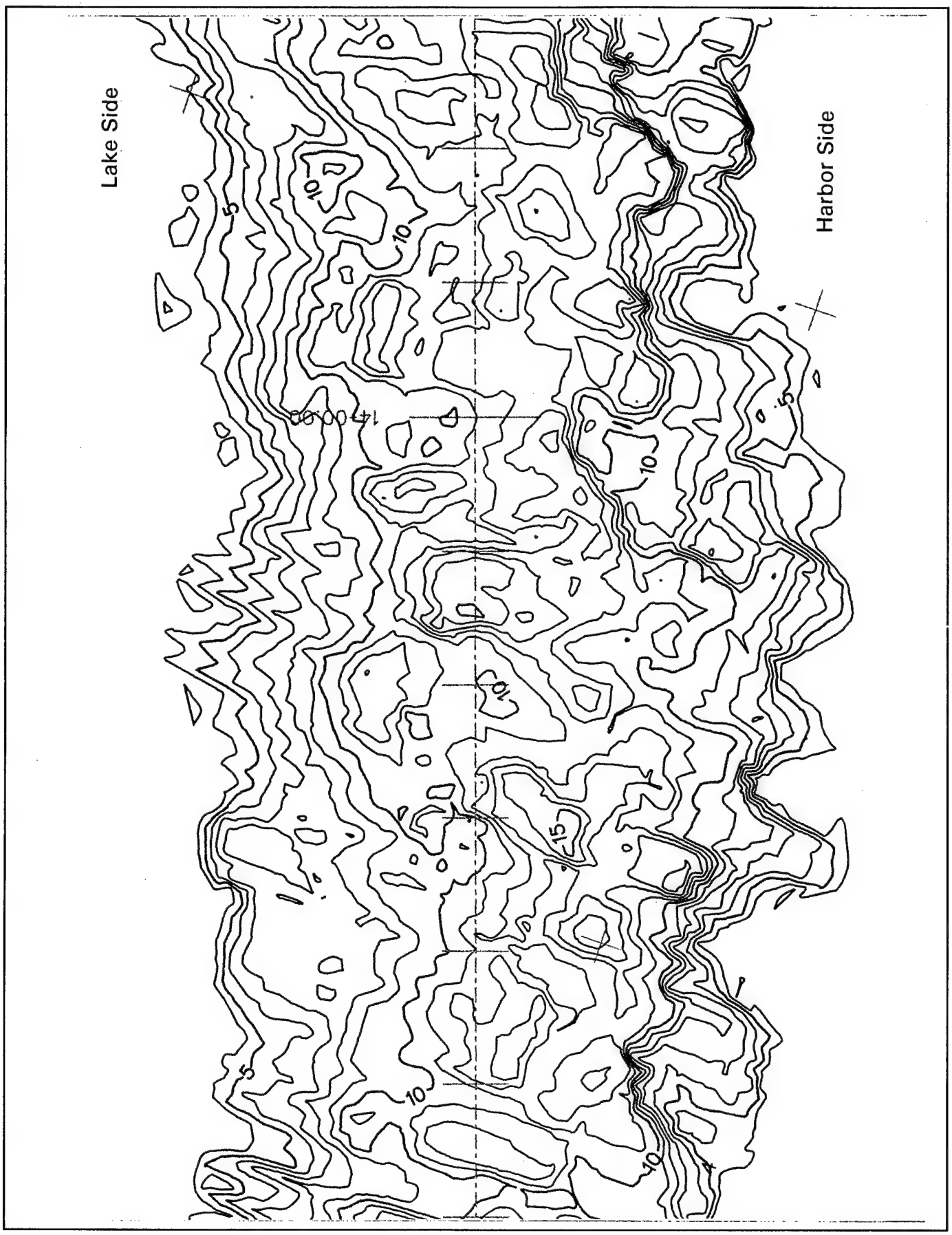


Figure A17. Topography of Burns Harbor North Breakwater, sta 13+70-14+60

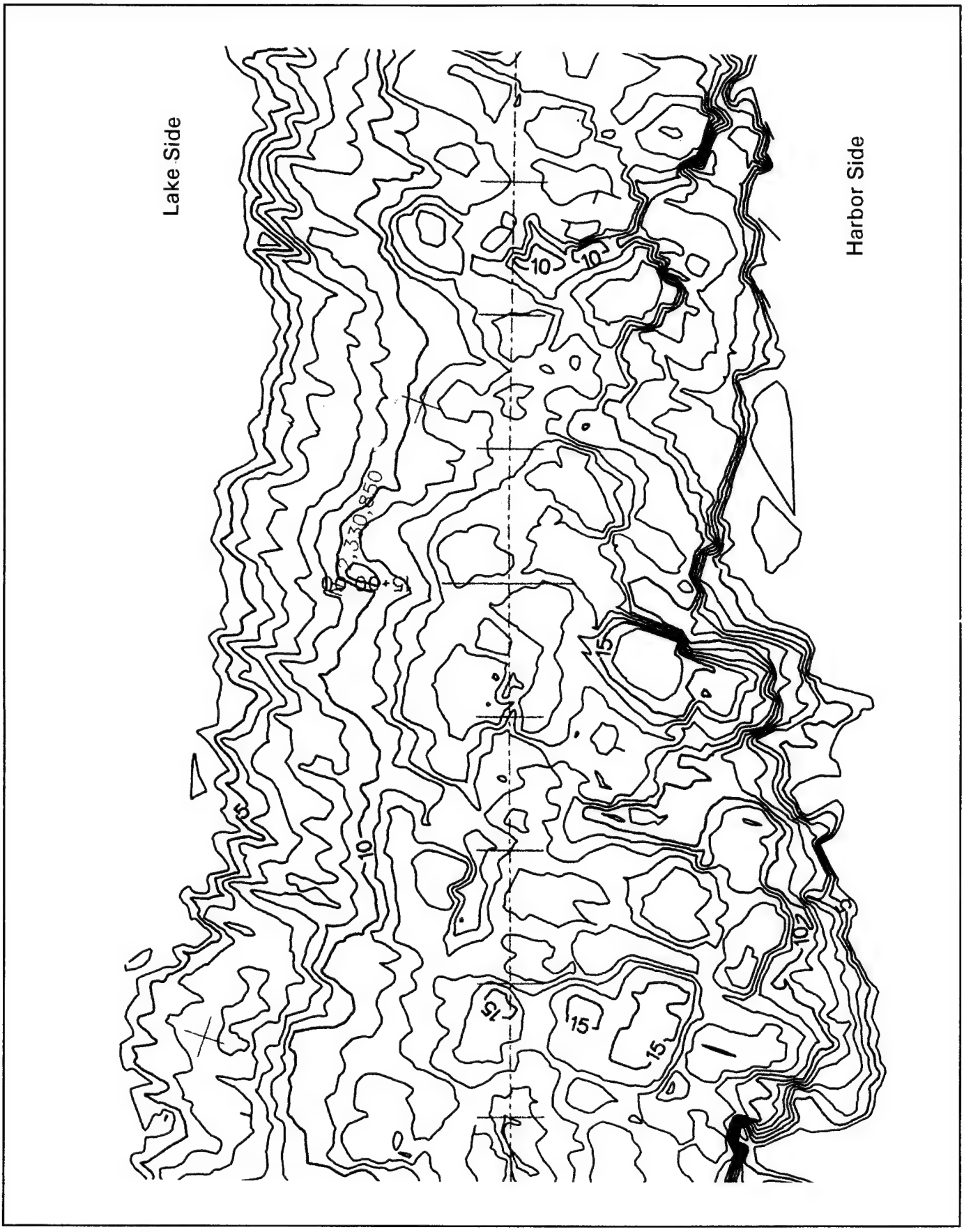


Figure A18. Topography of Burns Harbor North Breakwater, sta 14+60-15+45

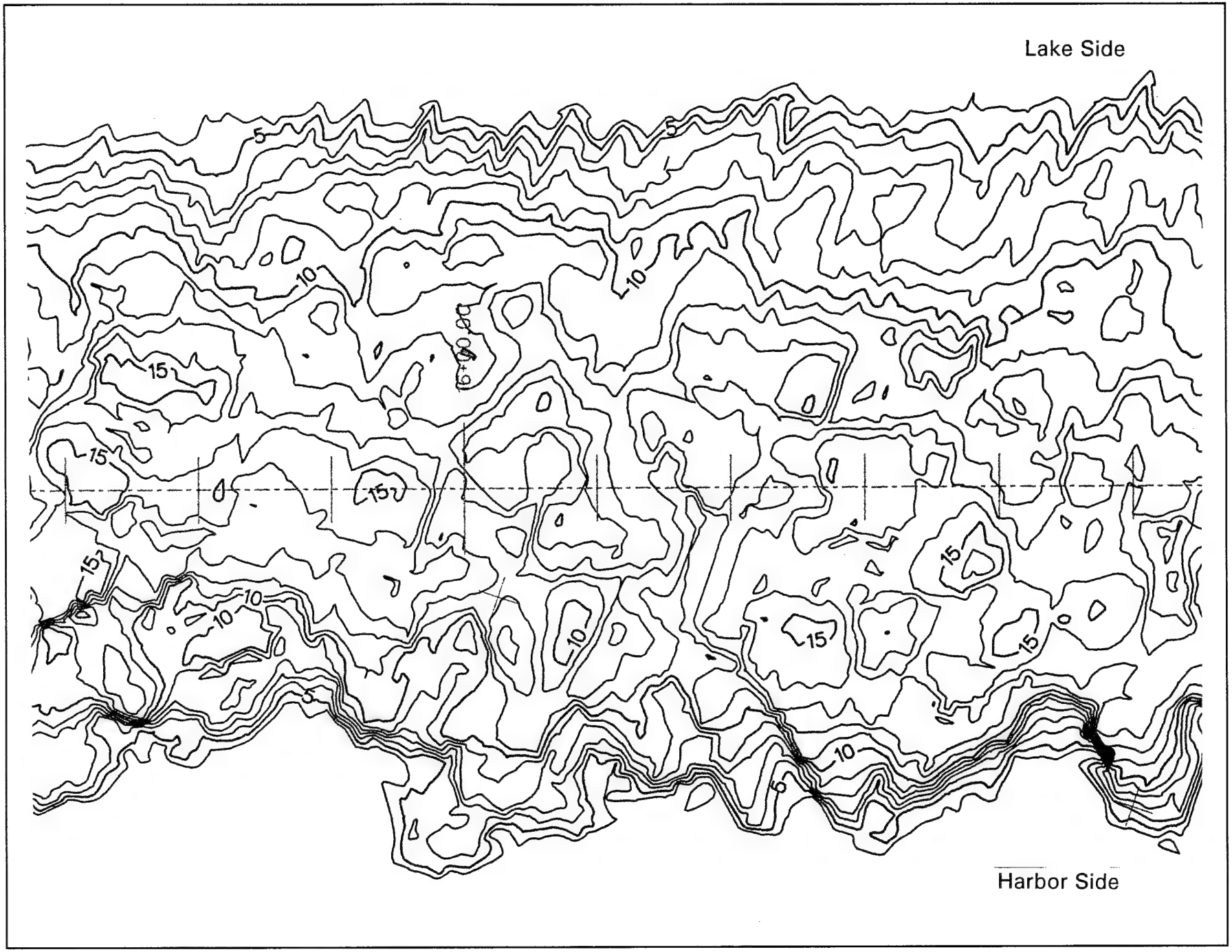


Figure A19. Topography of Burns Harbor North Breakwater, sta 15+45-16+33

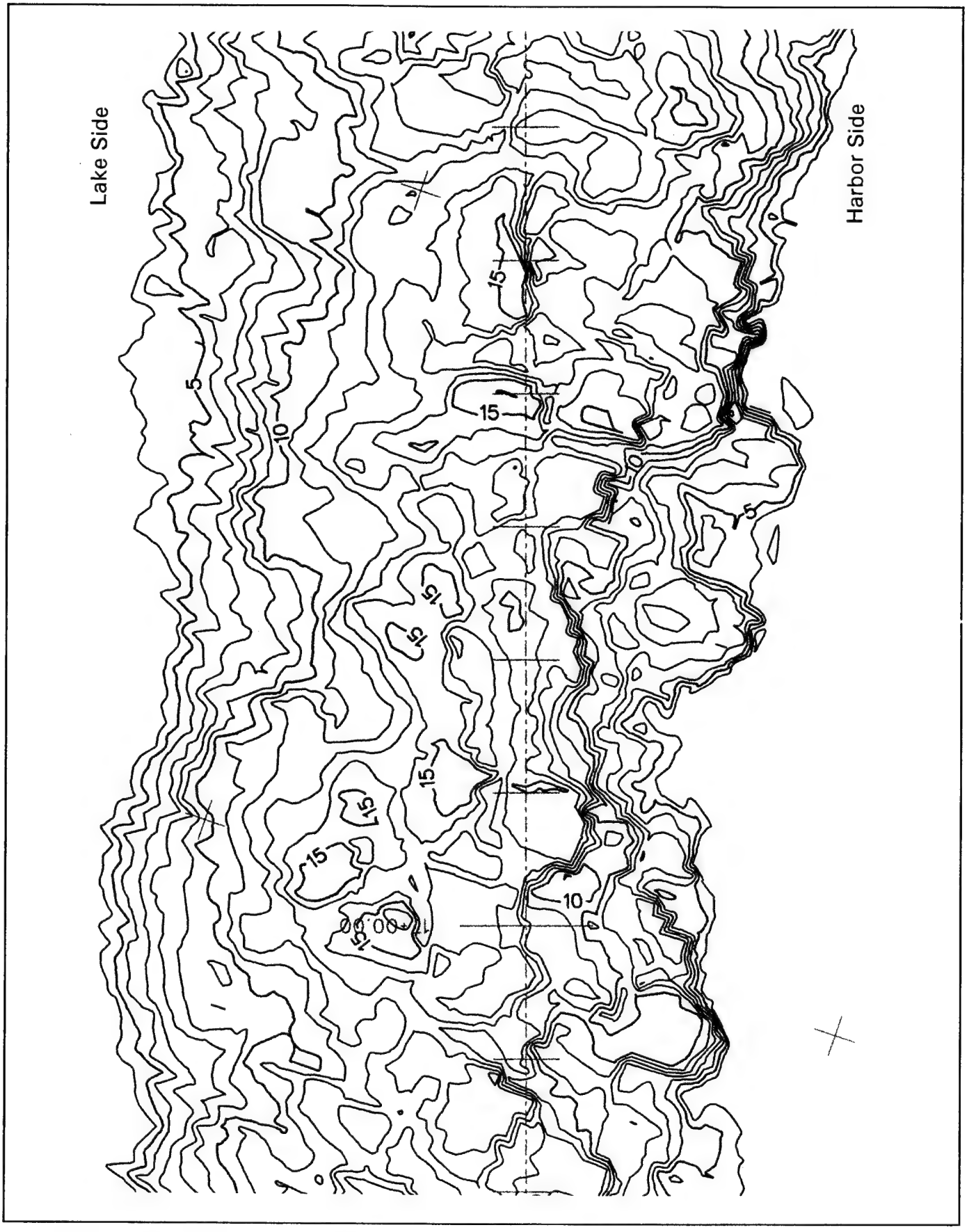


Figure A20. Topography of Burns Harbor North Breakwater, sta 16+33-17+20

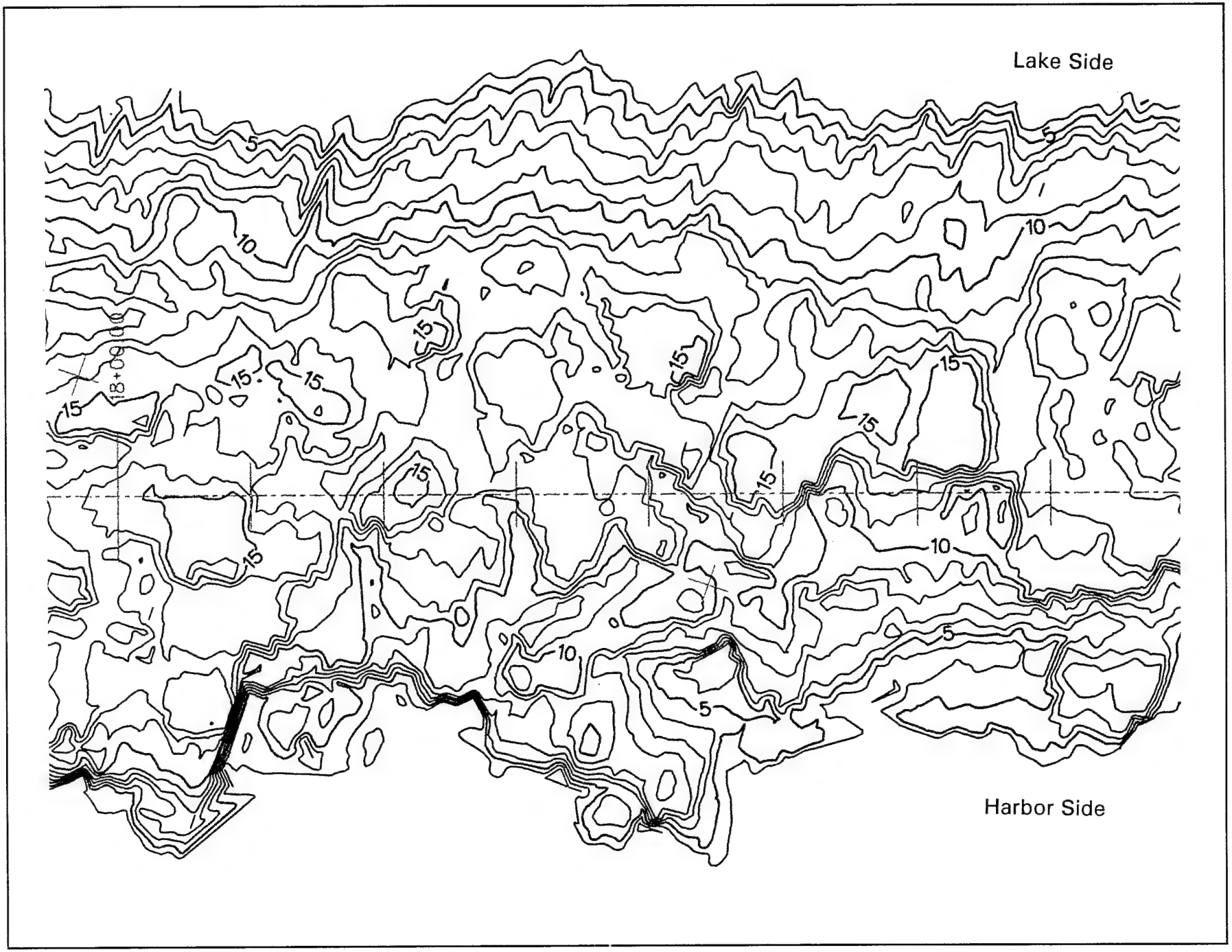


Figure A21. Topography of Burns Harbor North Brreakwater, sta 17+20-18+05

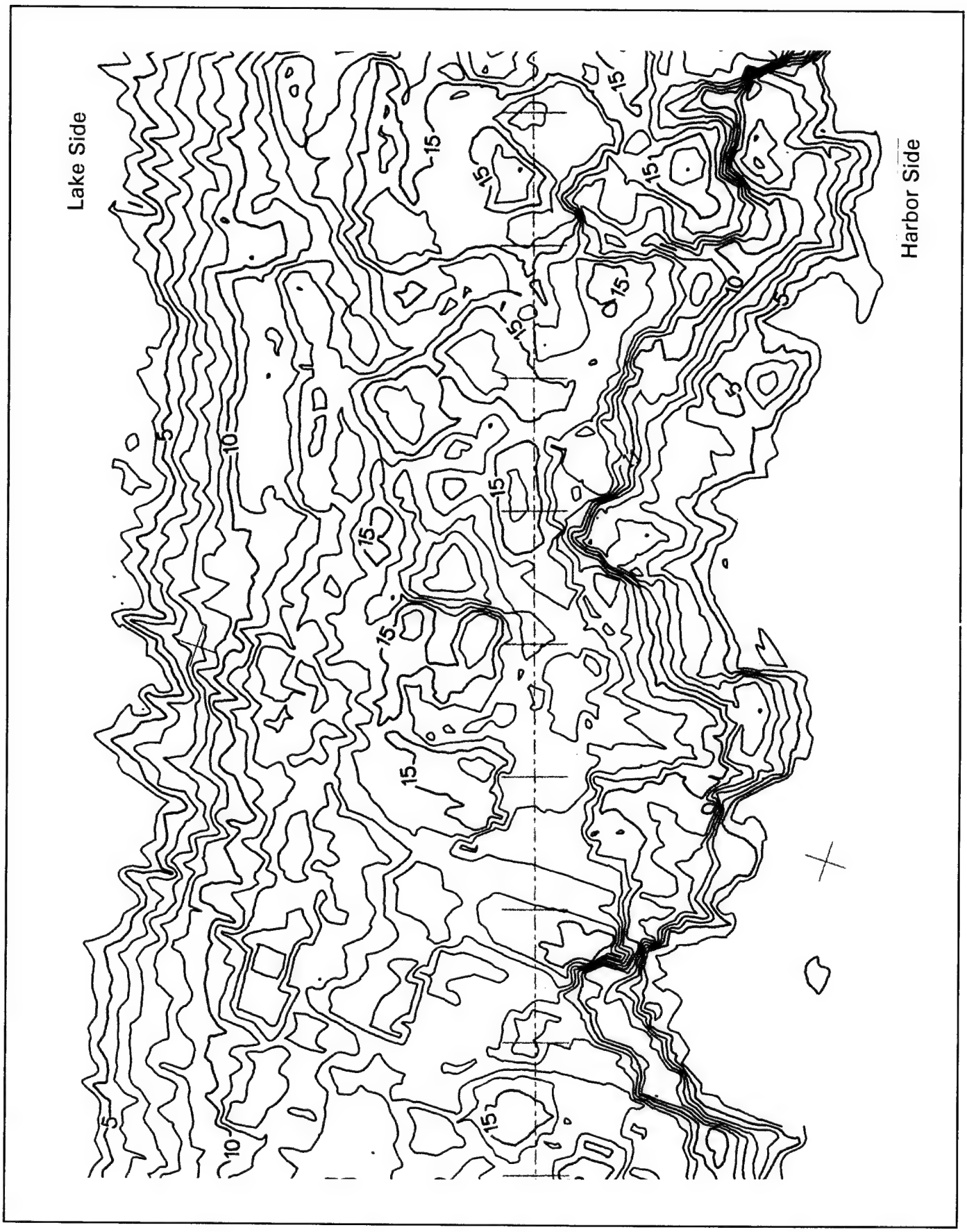


Figure A22. Topography of Burns Harbor North Breakwater, sta 18+05-18+90

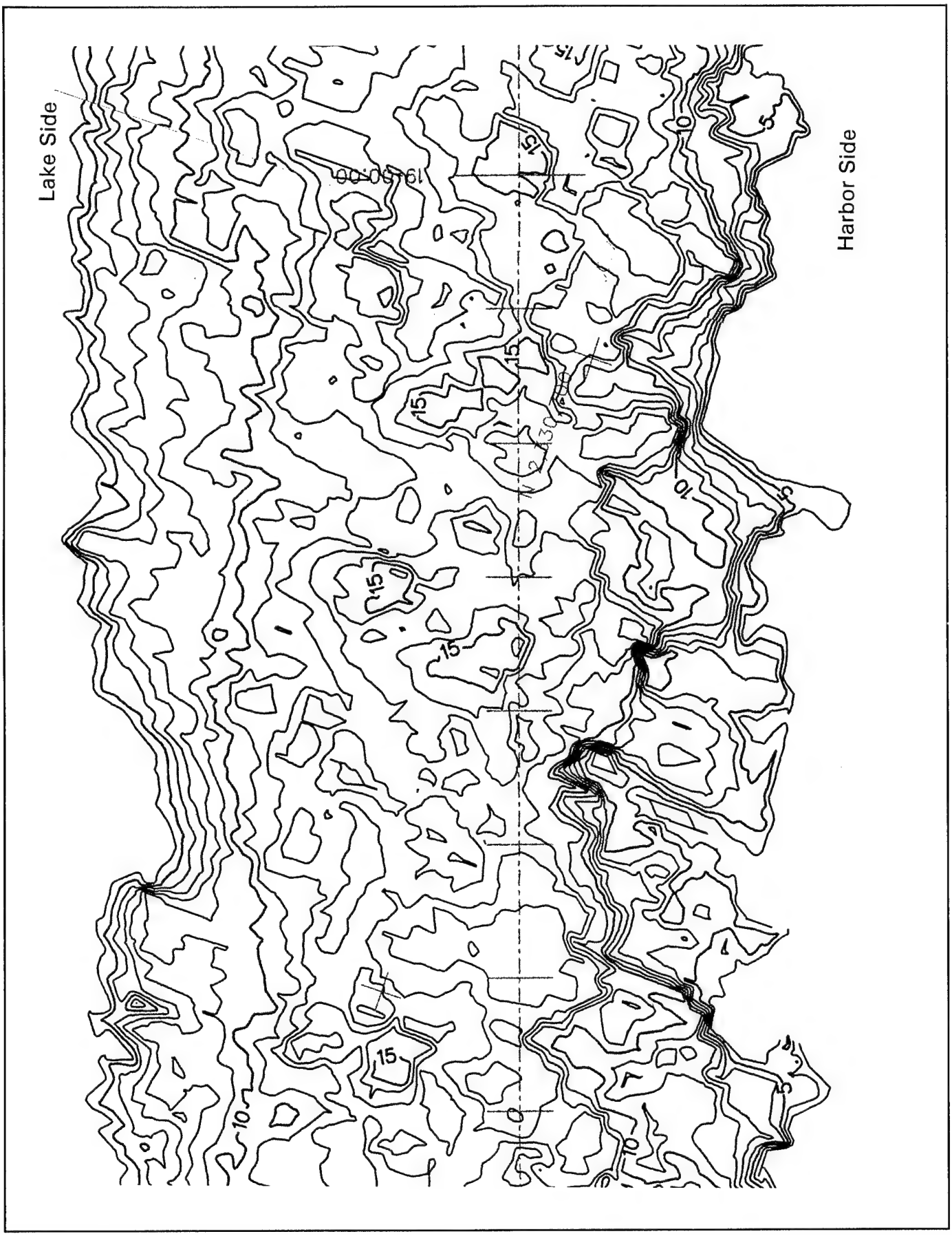


Figure A23. Topography of Burns Harbor North Breakwater, sta 18+90-19+76

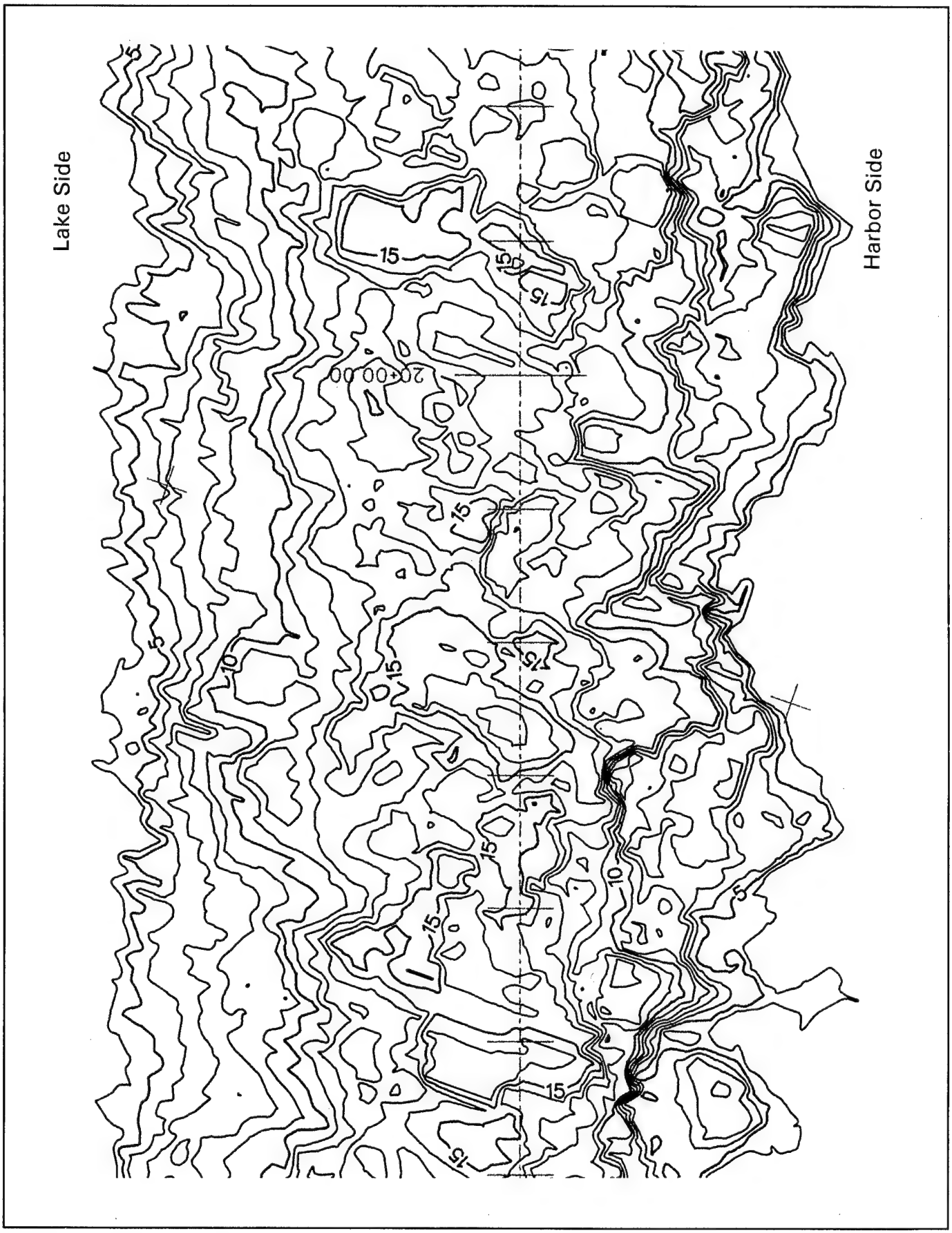


Figure A24. Topography of Burns Harbor North Breakwater, sta 19+76-20+60

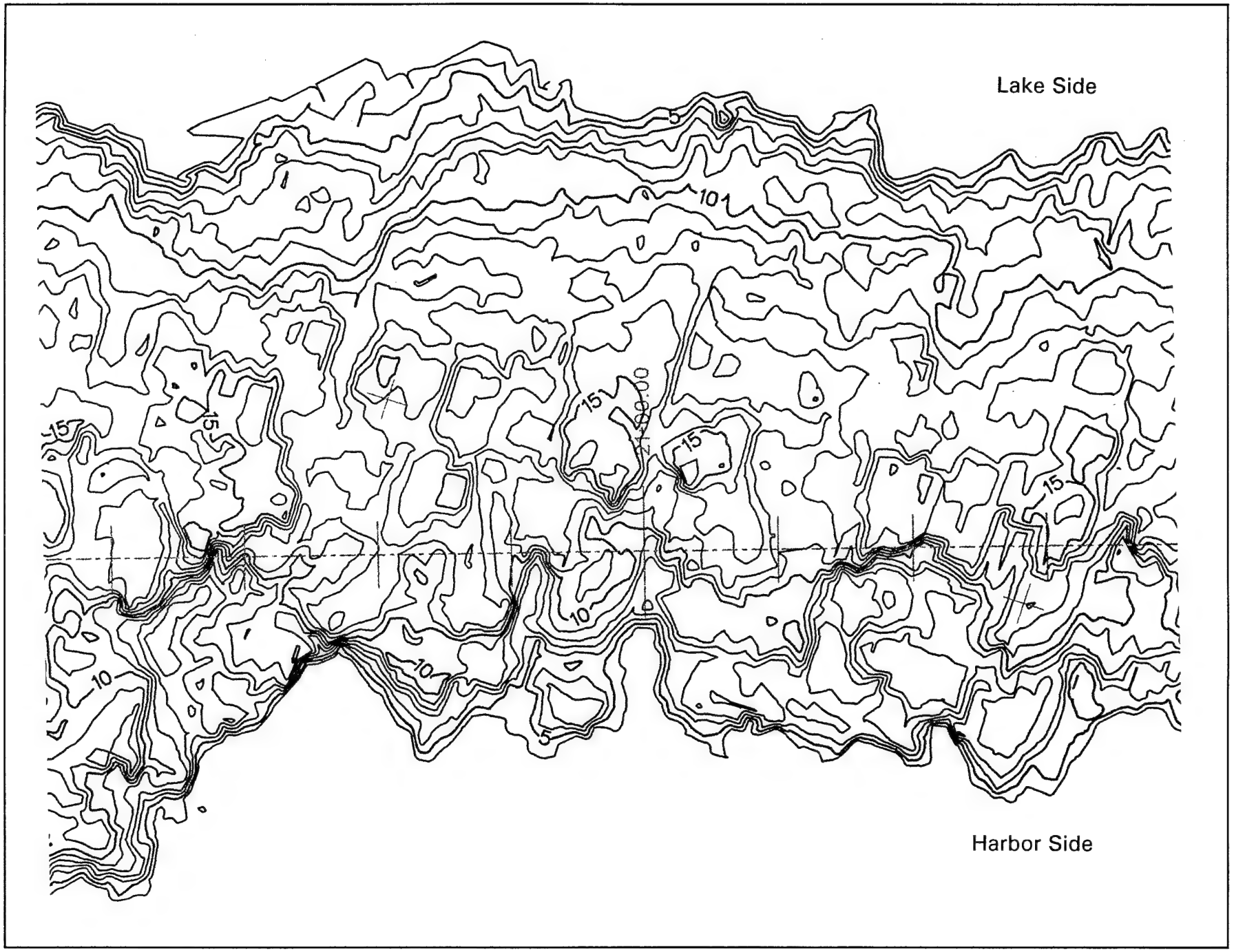


Figure A25. Topography of Burns Harbor North Breakwater, sta 20+60-21+45

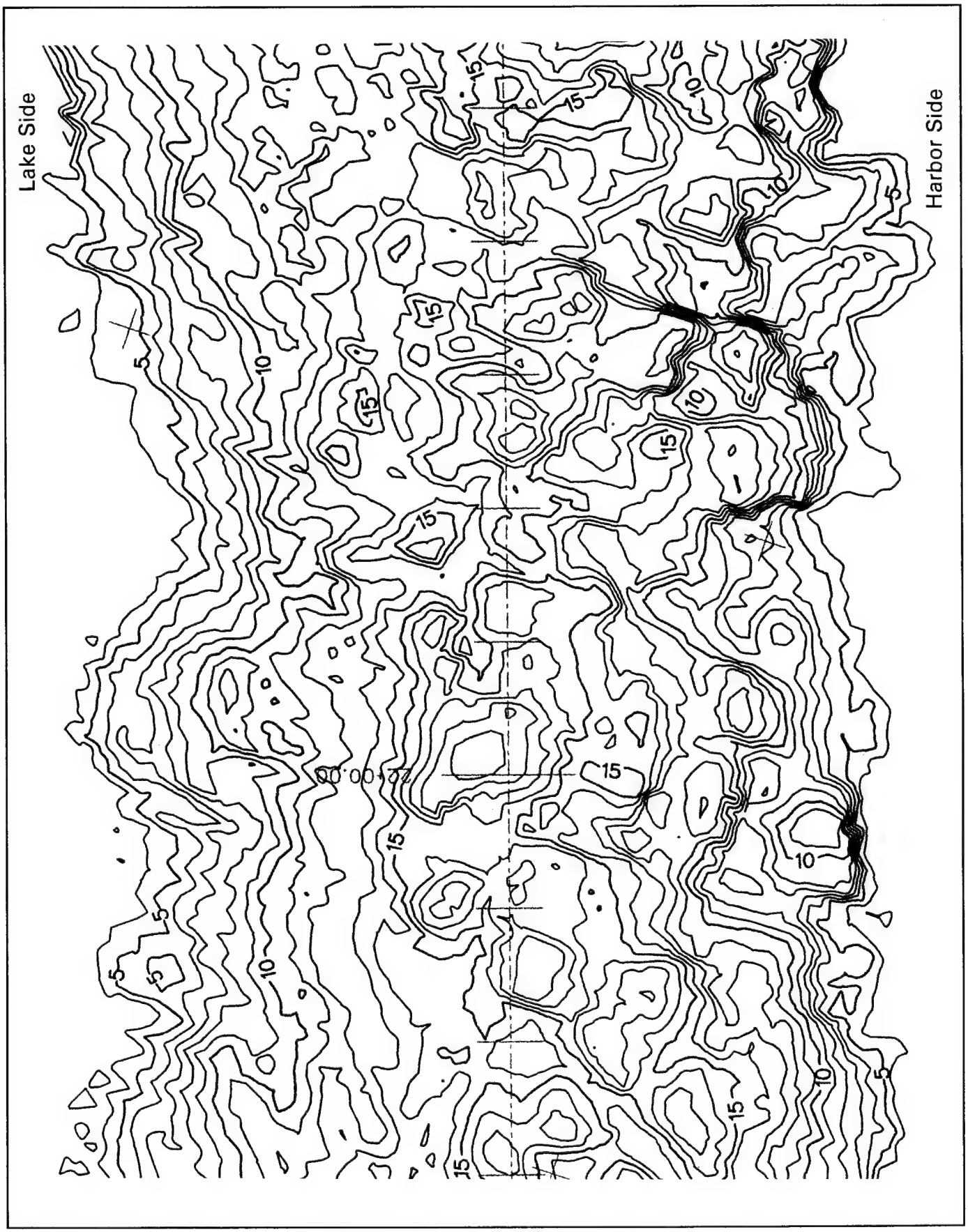


Figure A26. Topography of Burns Harbor North Breakwater, sta 21+45-22+30

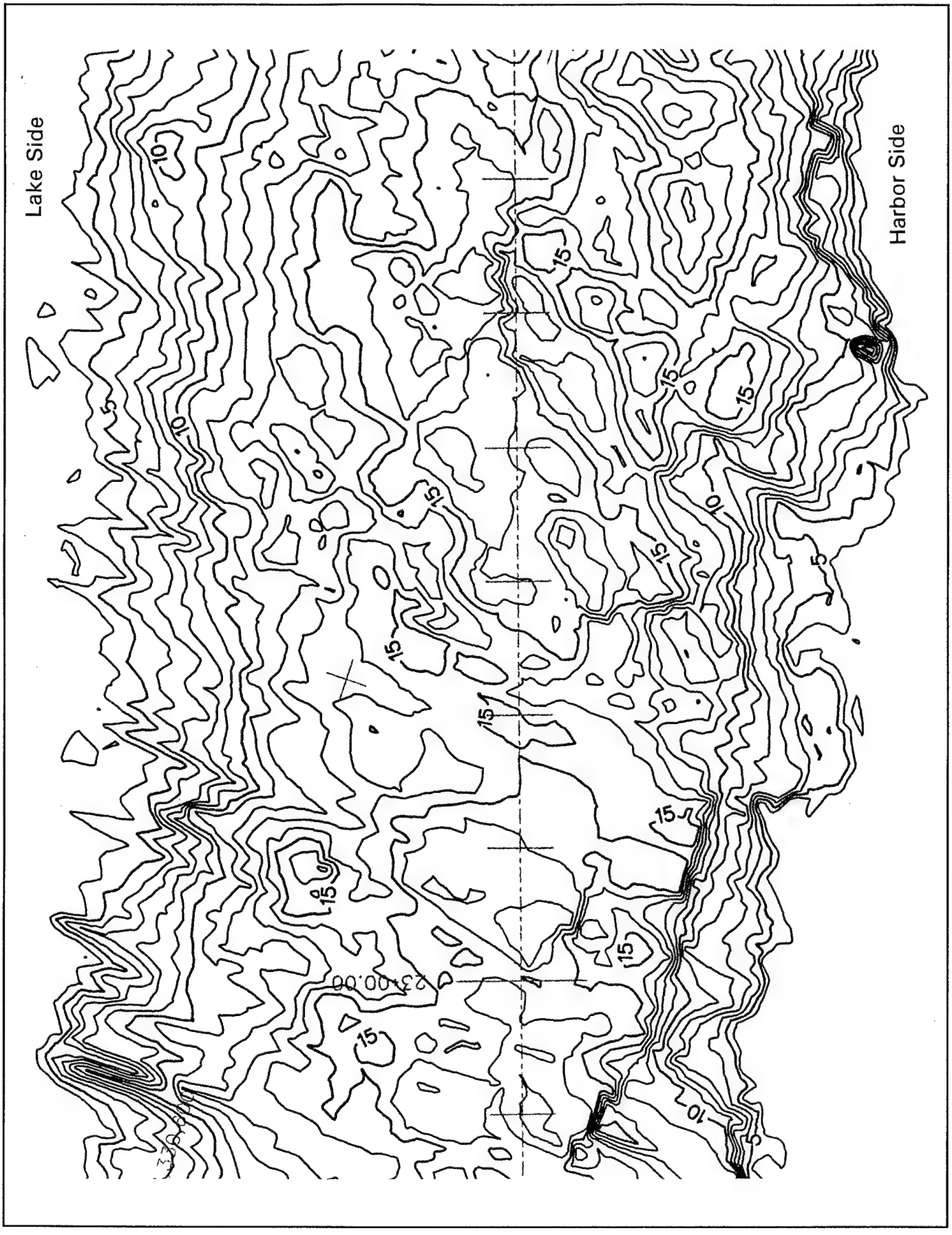


Figure A27. Topography of Burns Harbor North Breakwater, sta 22+30-23+15

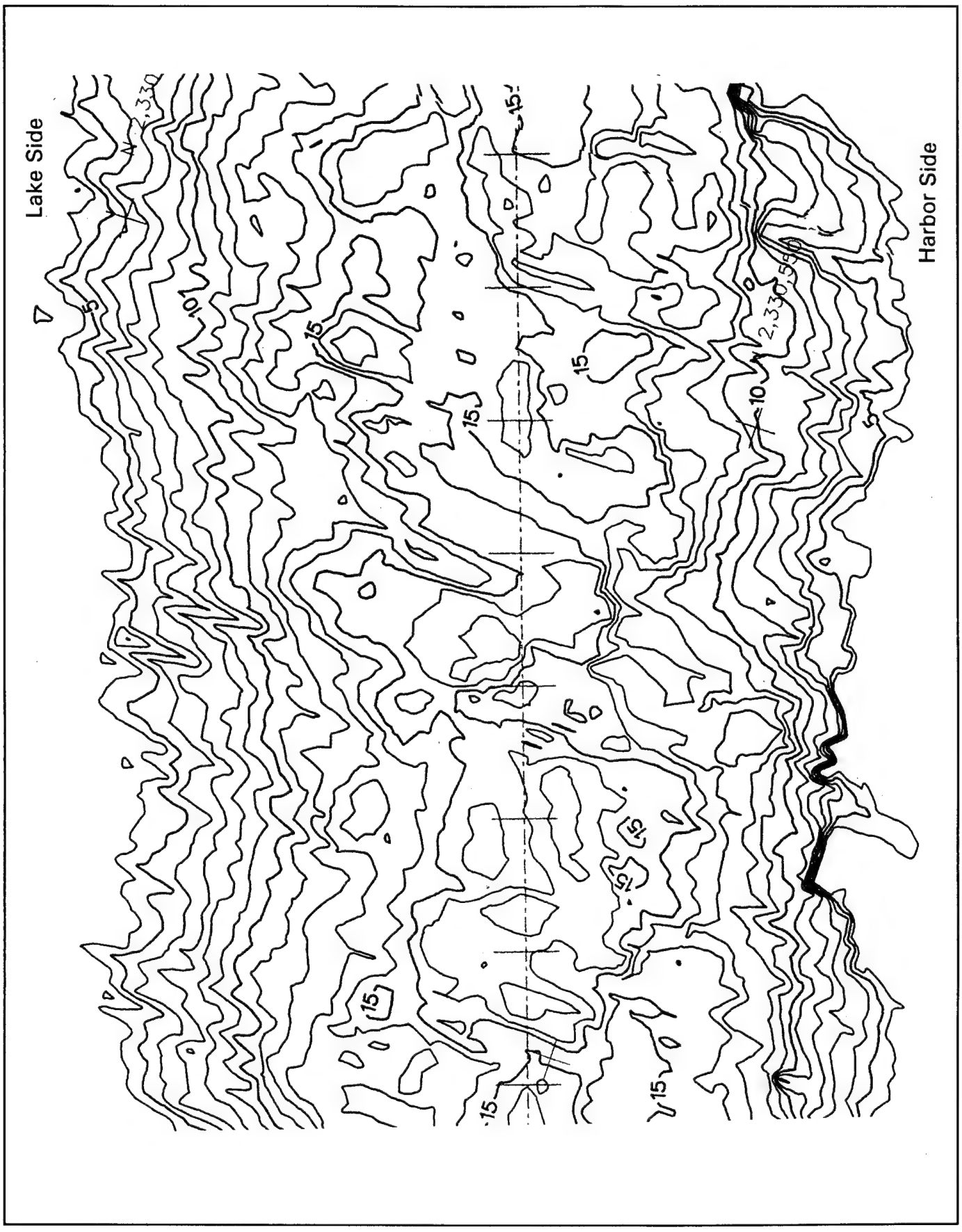


Figure A28. Topography of Burns Harbor North Breakwater, sta 23+15-23+93

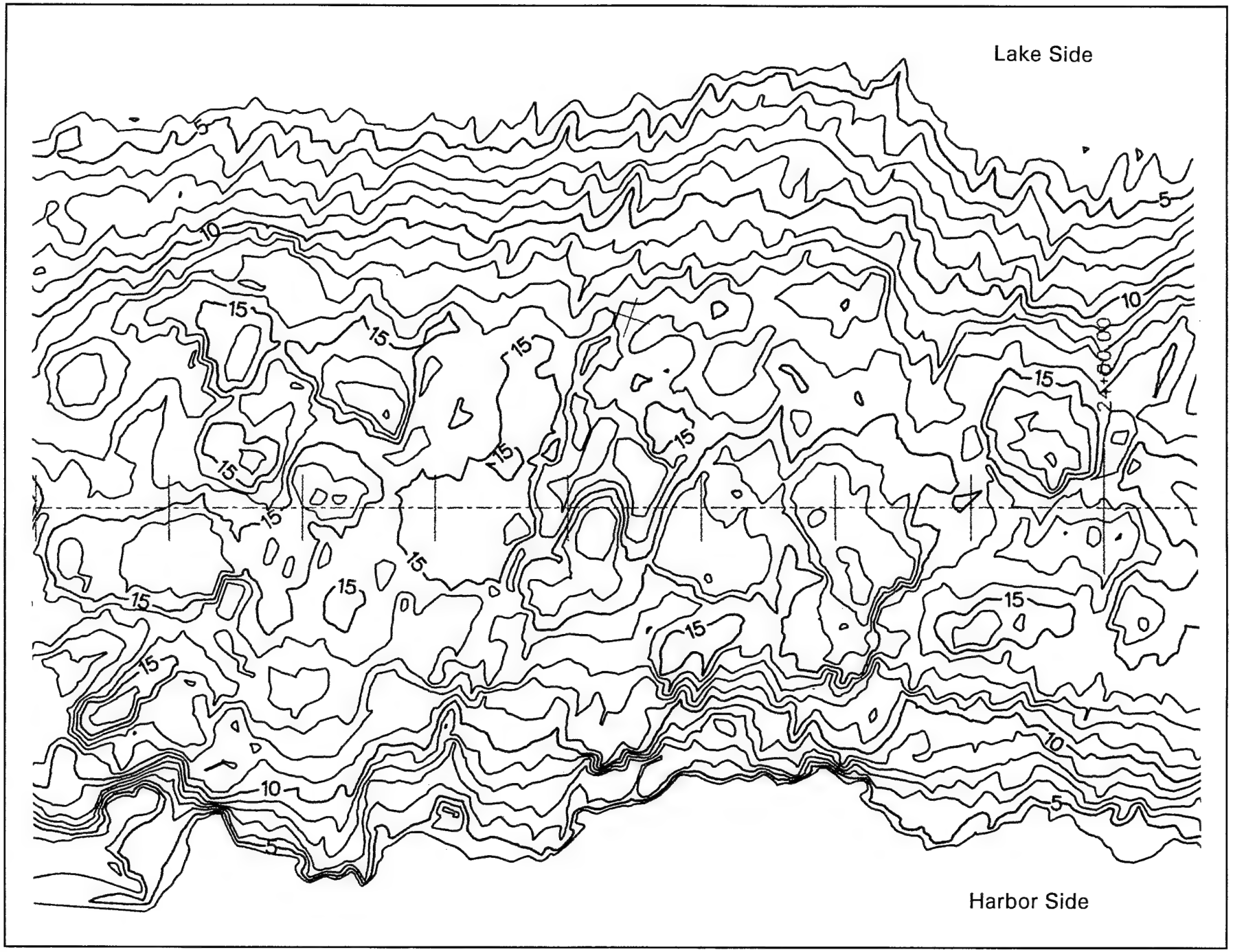


Figure A29. Topography of Burns Harbor North Breakwater, sta 23+93-24+80

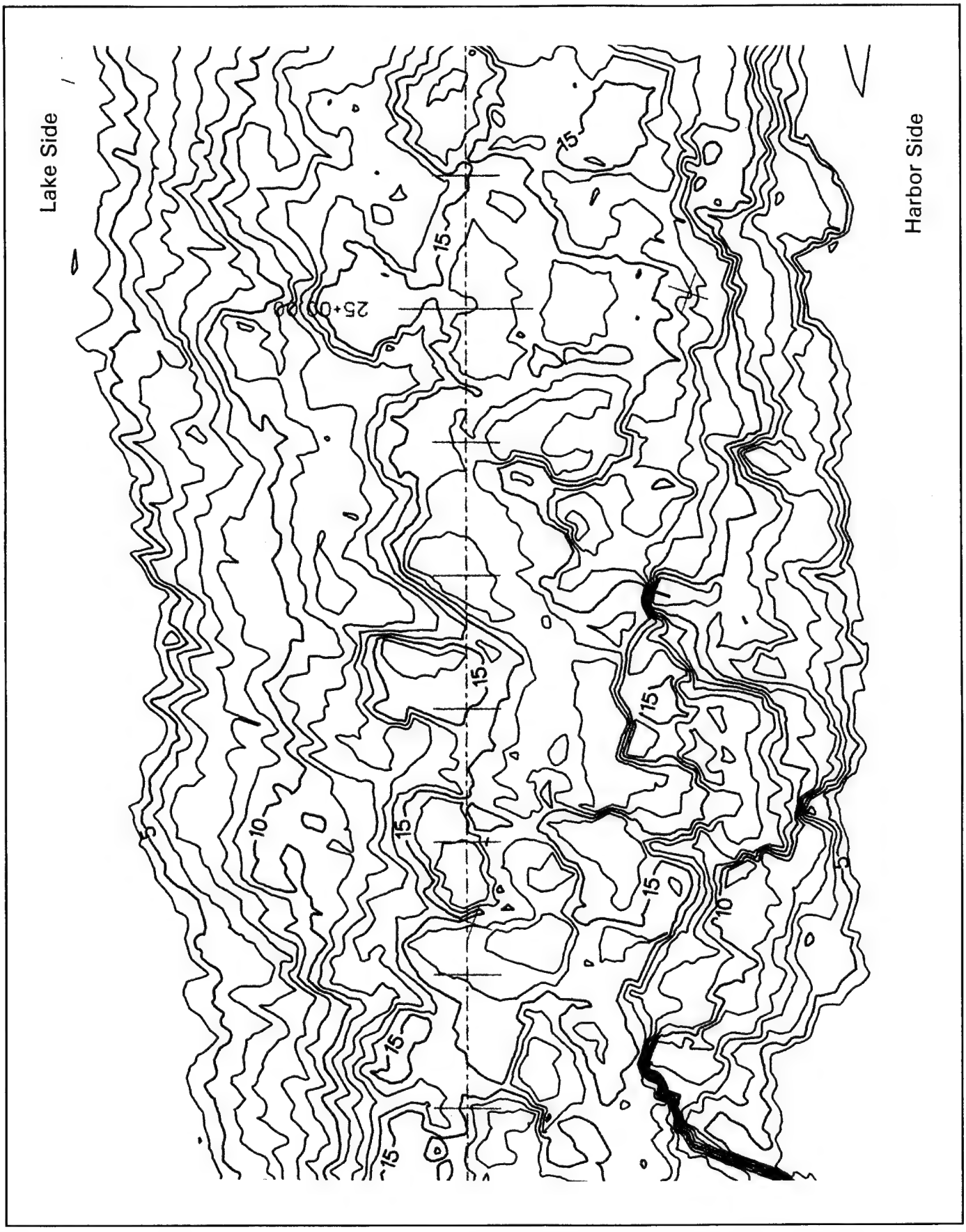


Figure A30. Topography of Burns Harbor North Breakwater, sta 24+80-25+65

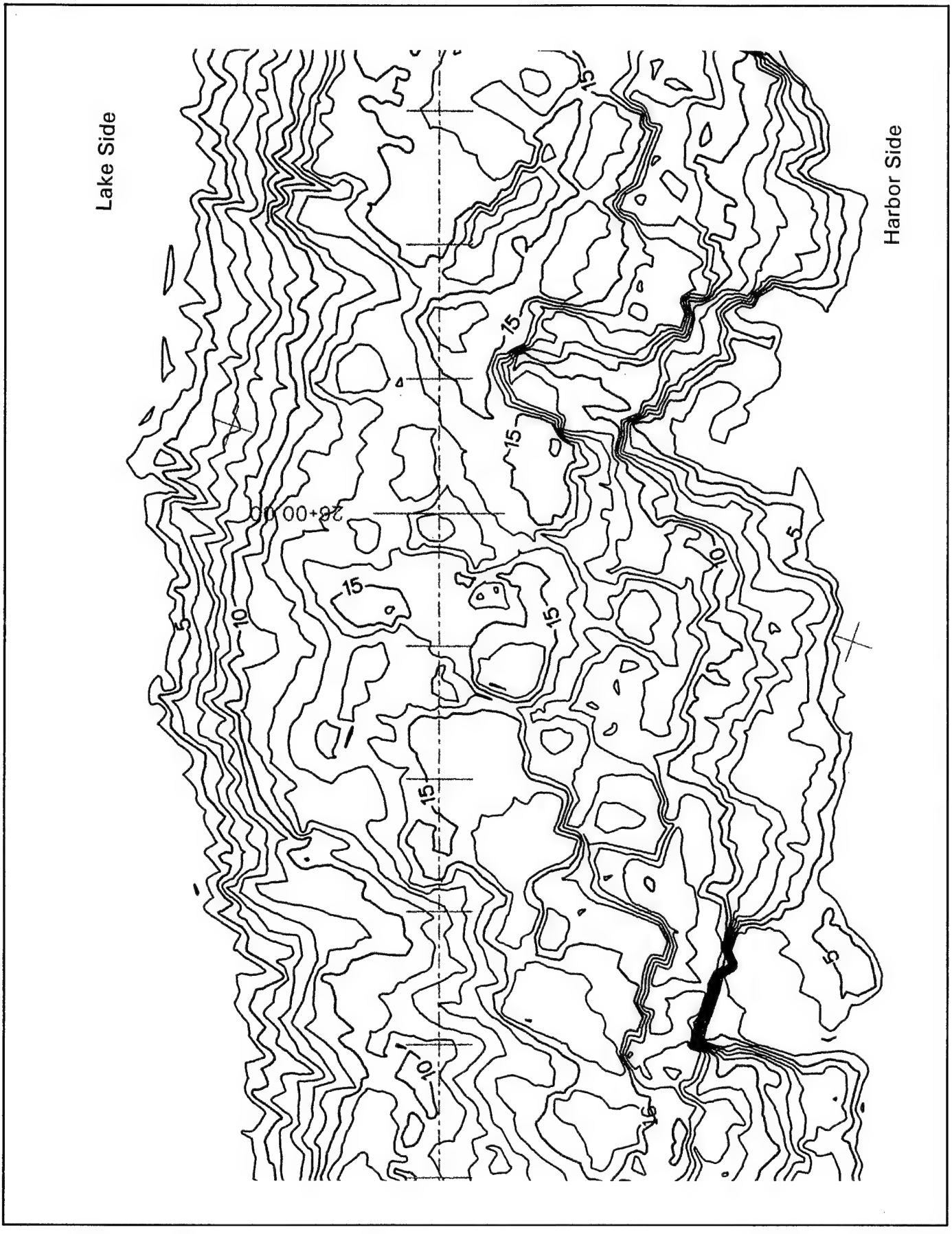


Figure A31. Topography of Burns Harbor North Breakwater, sta 25+65-26+50

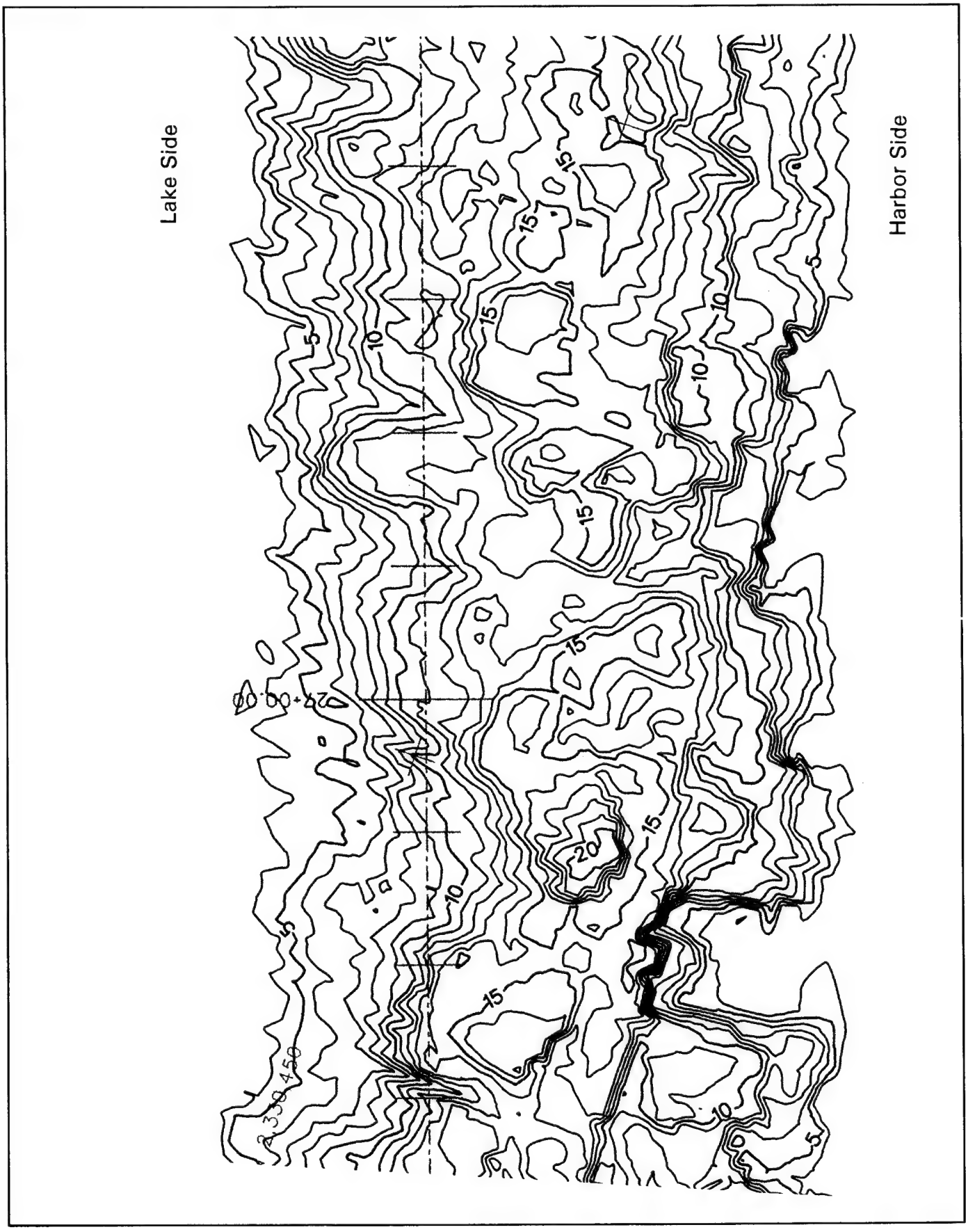


Figure A32. Topography of Burns Harbor North Breakwatrer, sta 2€+50-27+36

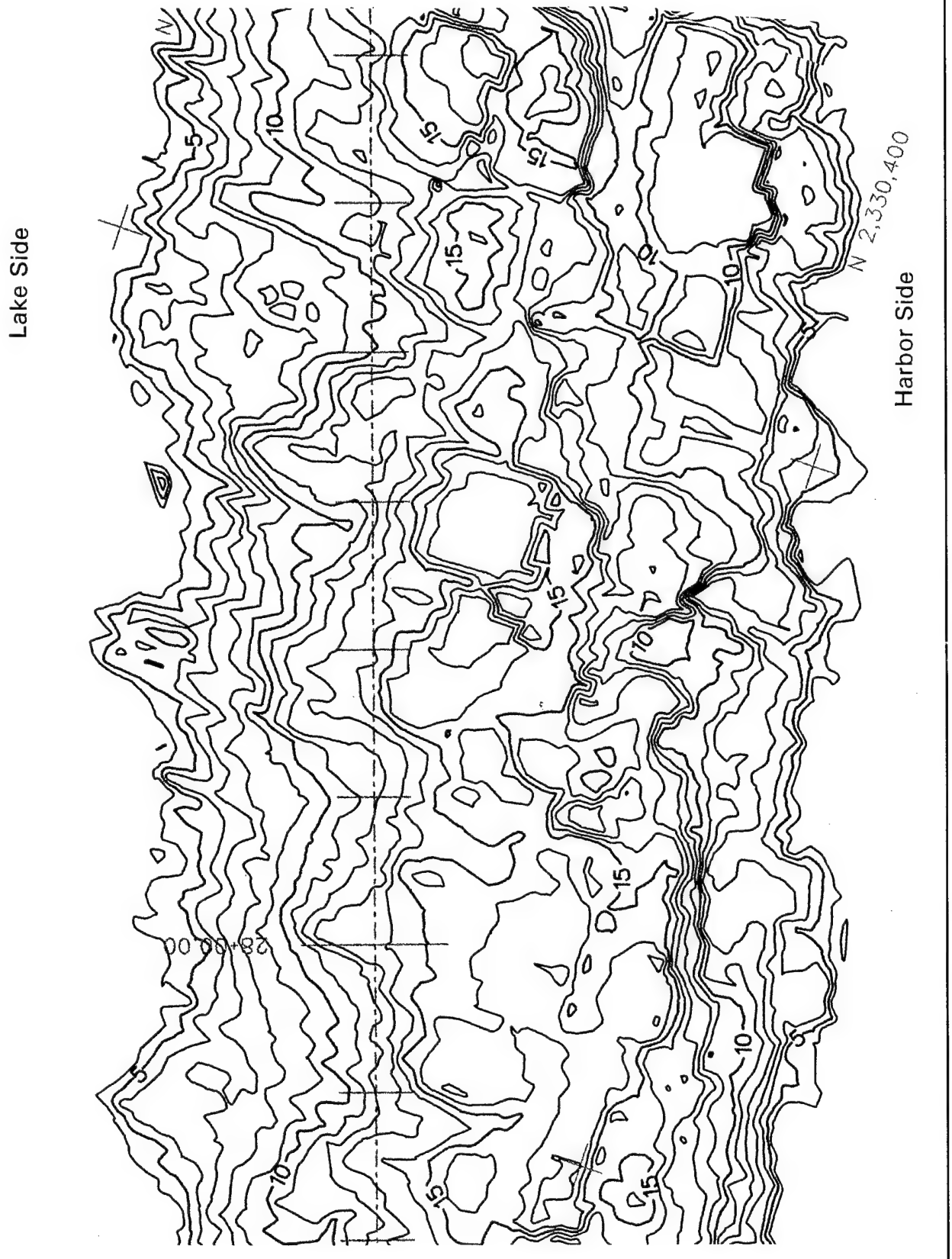


Figure A33. Topography of Burns Harbor North Breakwater, sta 27+36-28+20

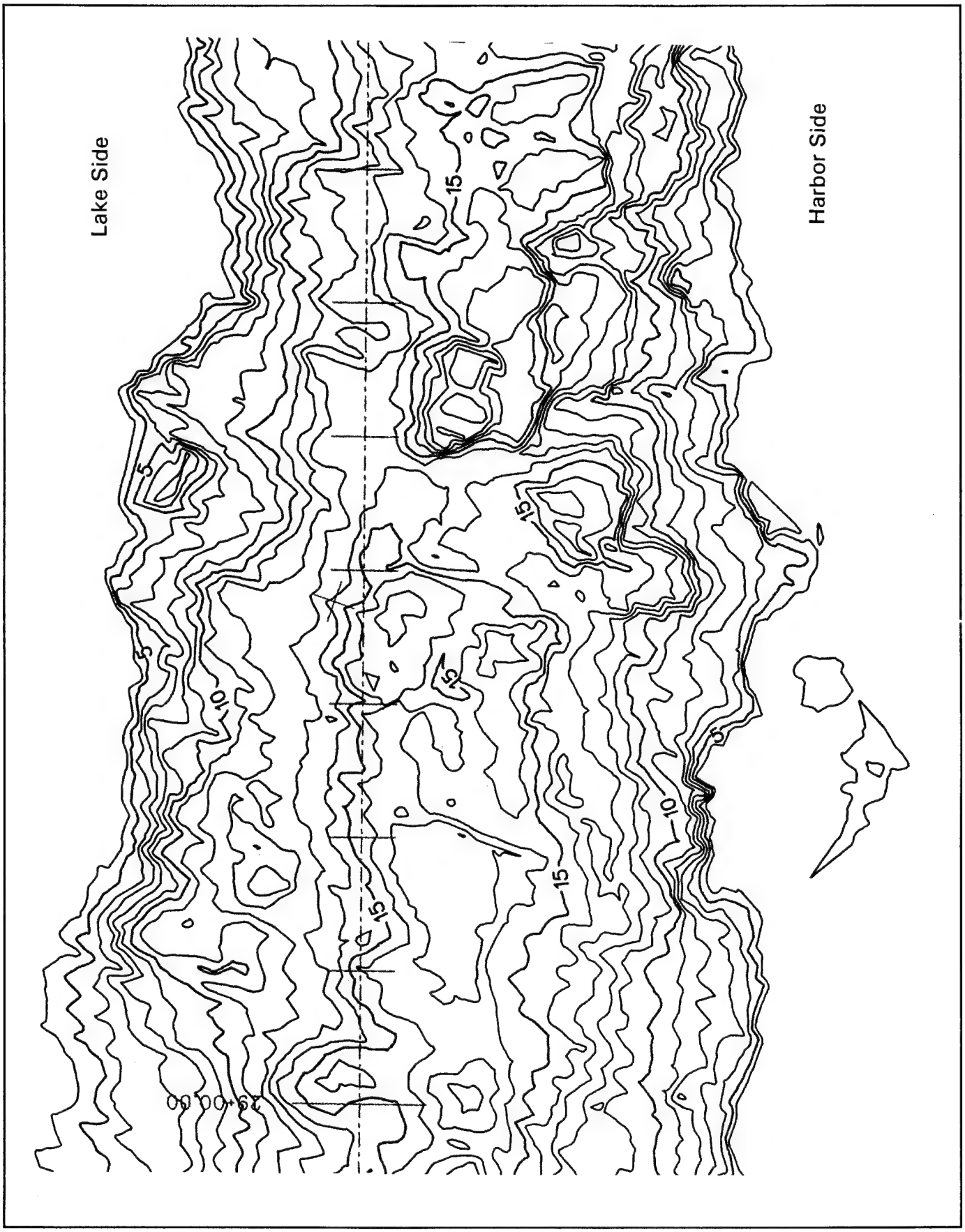


Figure A34. Topography of Burns Harbor North Breakwater, sta 28+20-29+05

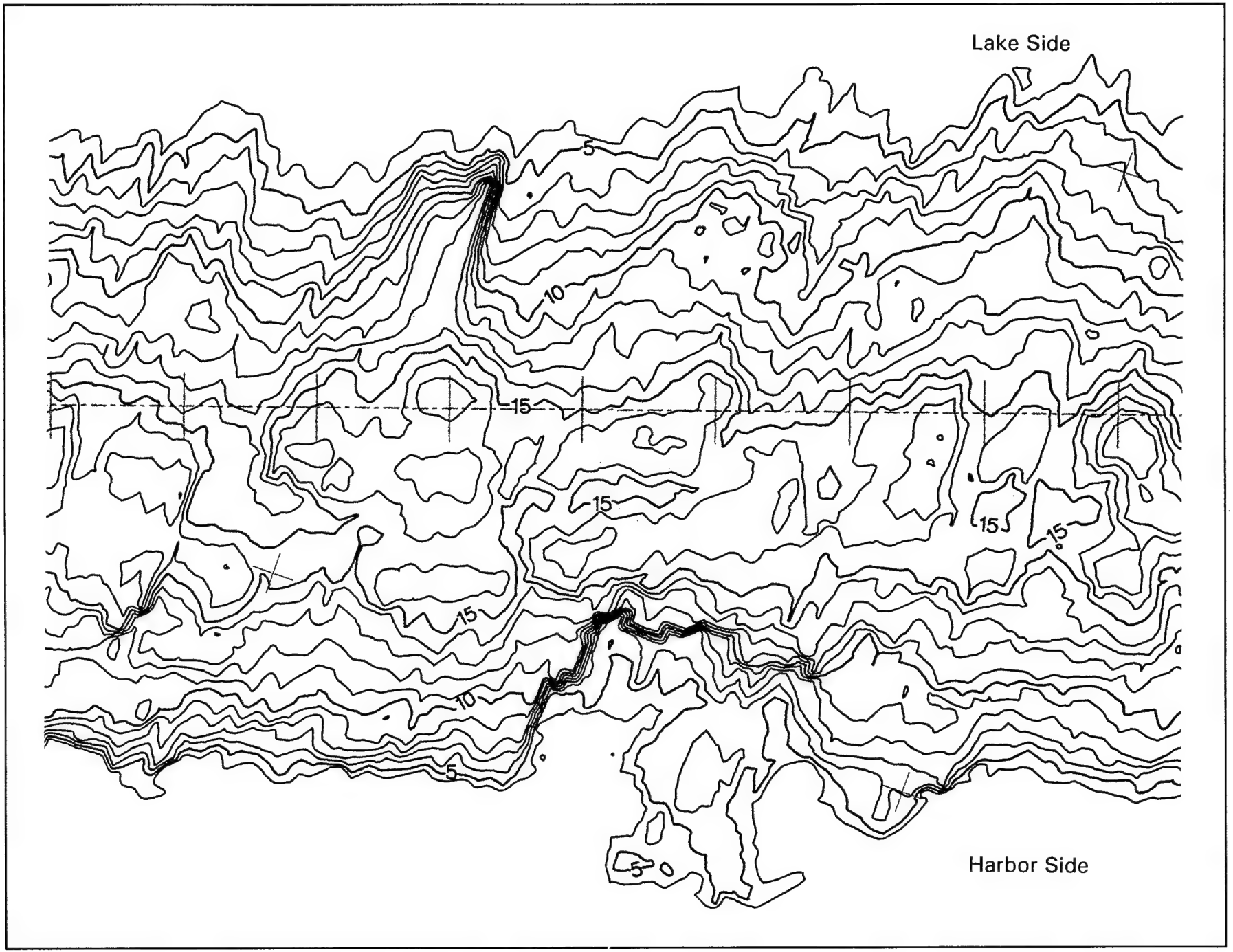


Figure A35. Topography of Burns Harbor North Breakwater, sta 29+05-29+90

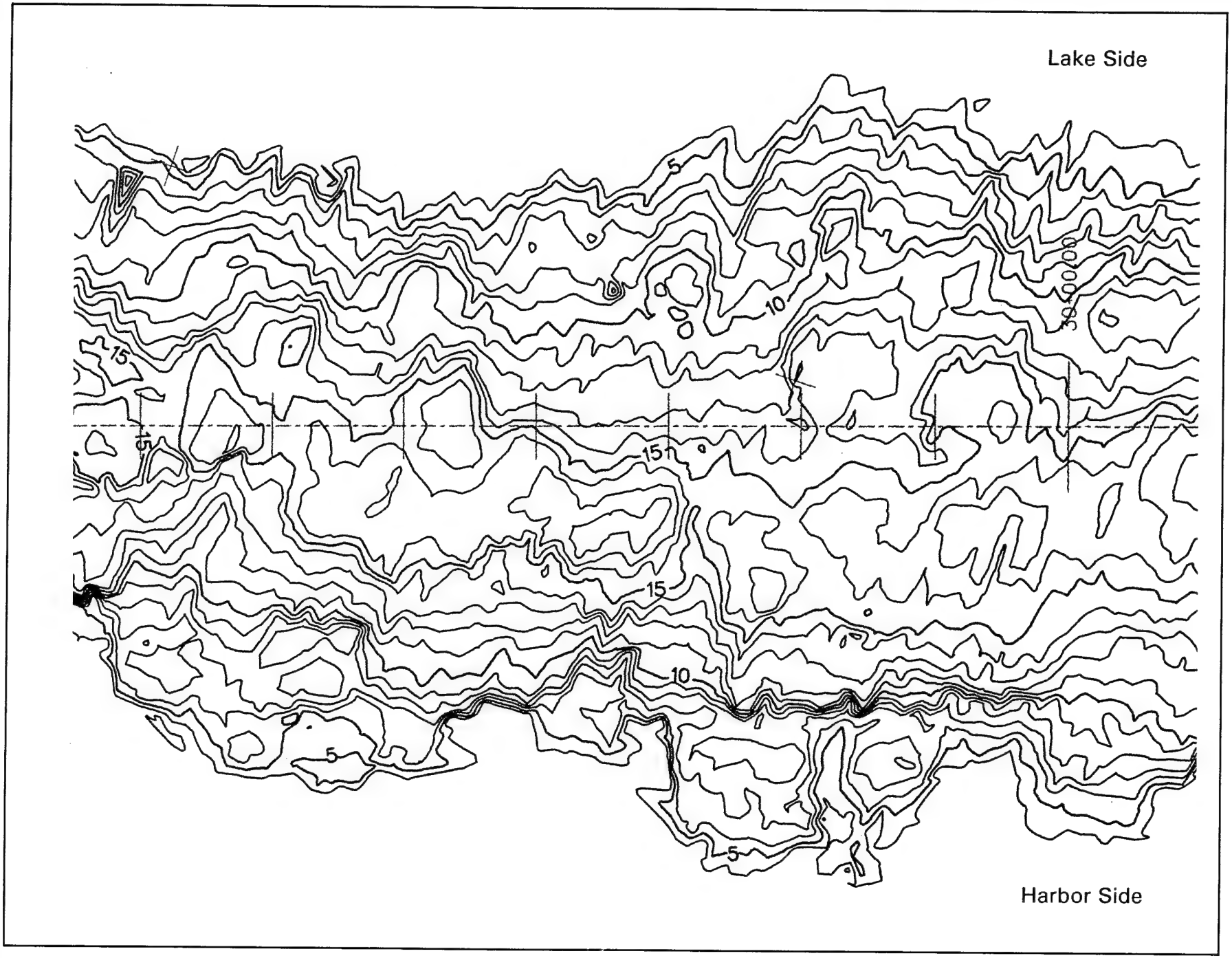


Figure A36. Topography of Burns Harbor North Breakwater, sta 29+90-30+75

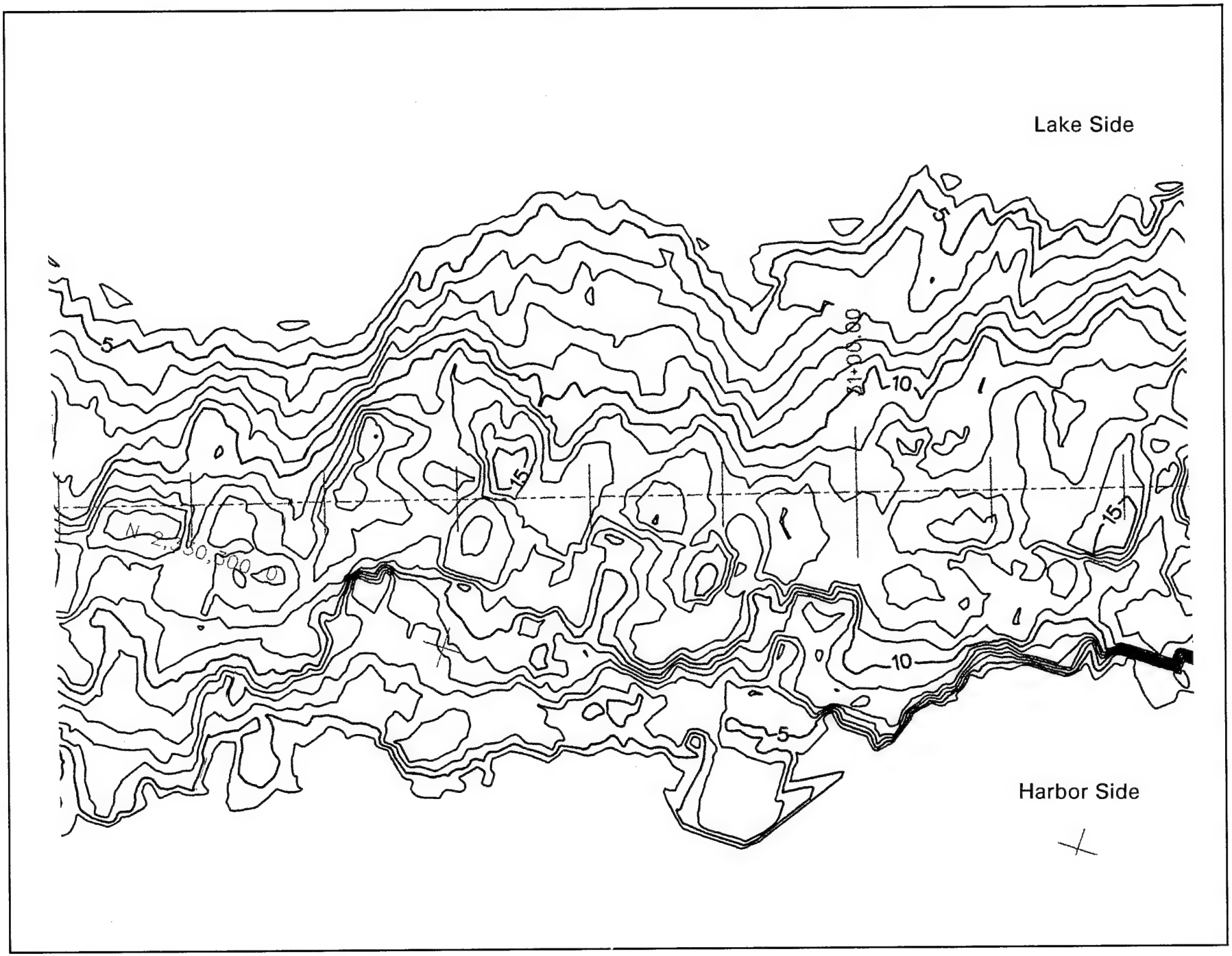


Figure A37. Topography of Burns Harbor North Breakwater, sta 30+75-31+60

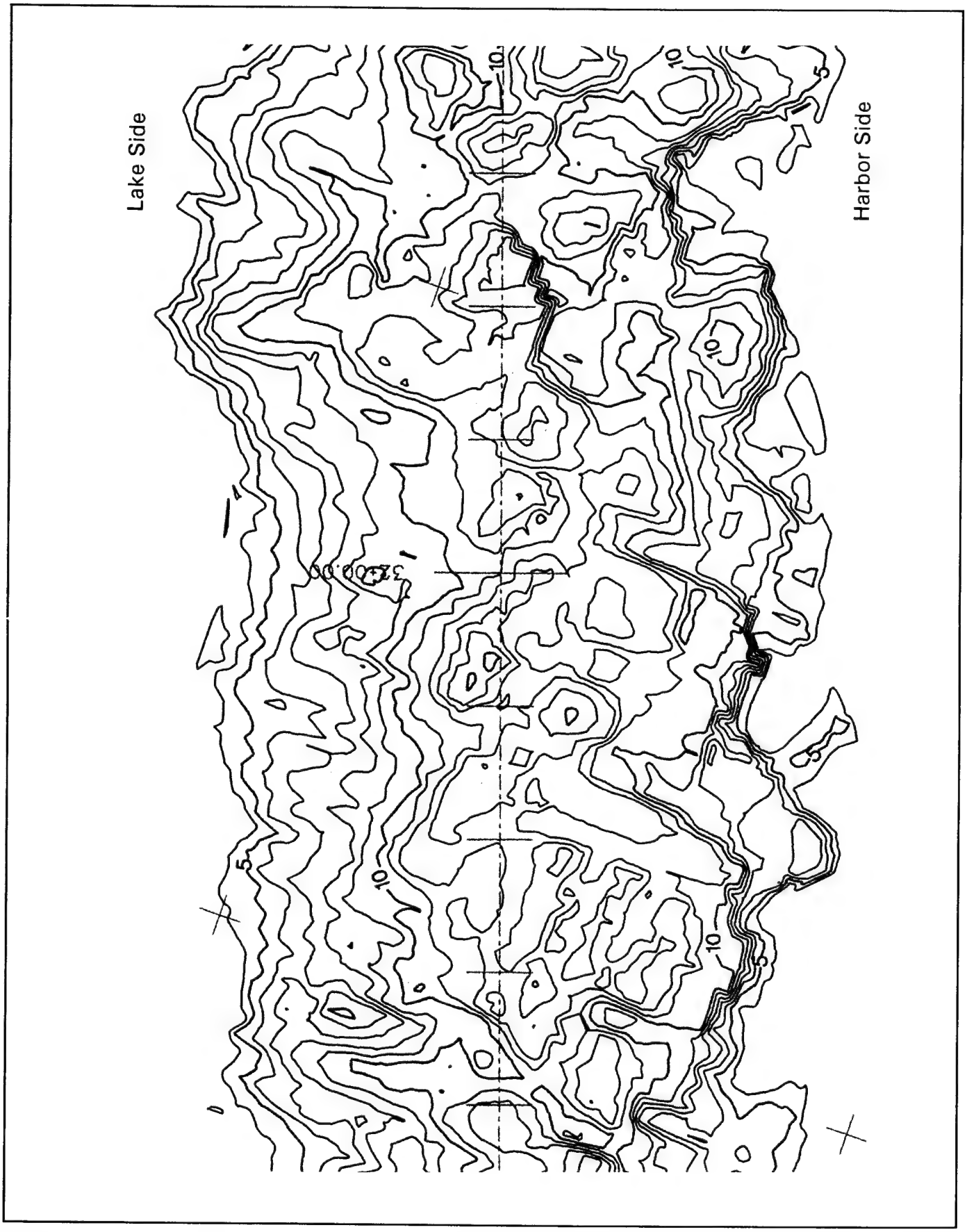


Figure A38. Topography of Burns Harbor North Breakwater, sta 31+60-32+45

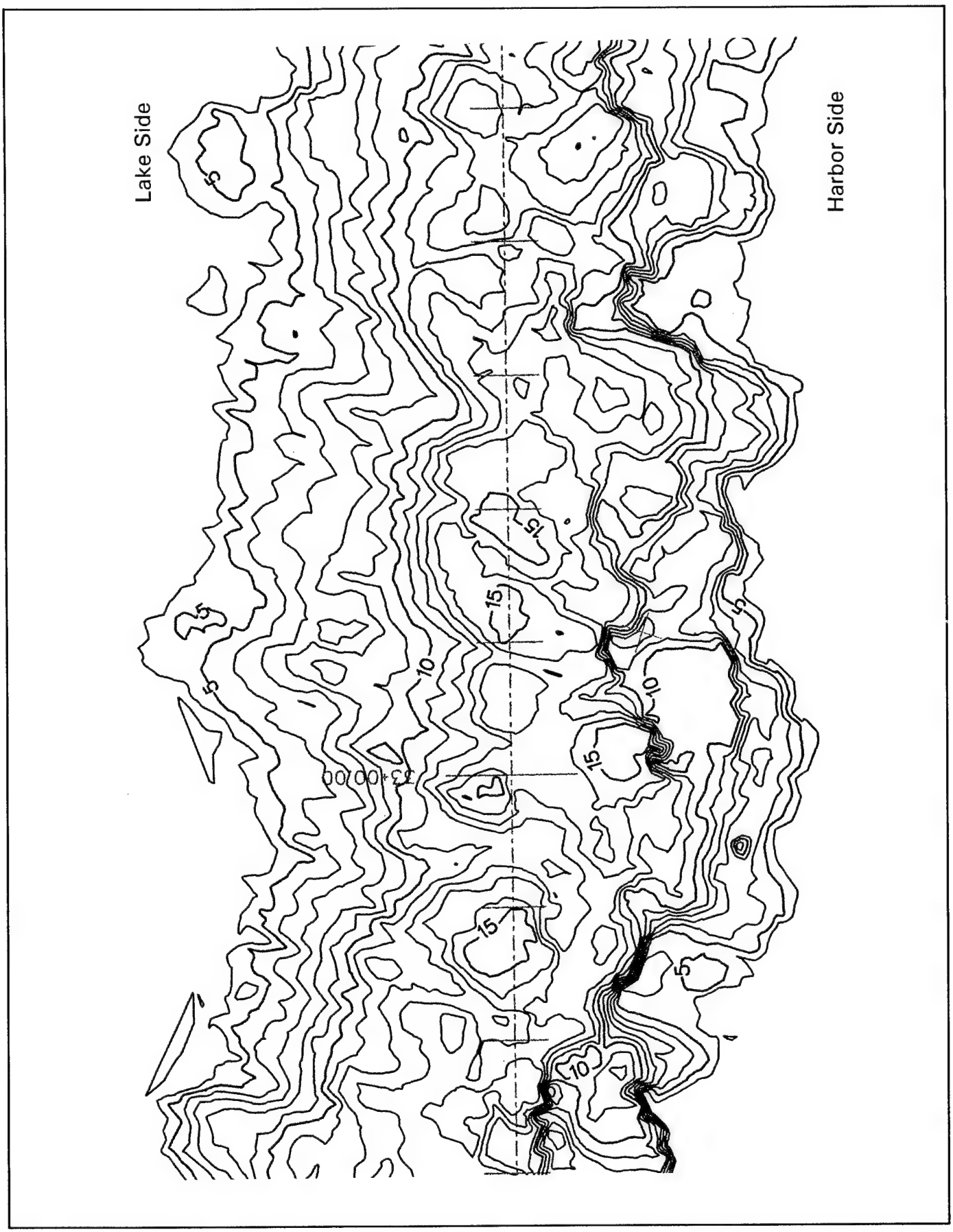


Figure A39. Topography of Burns Harbor North Breakwater, sta 32+45-33+30

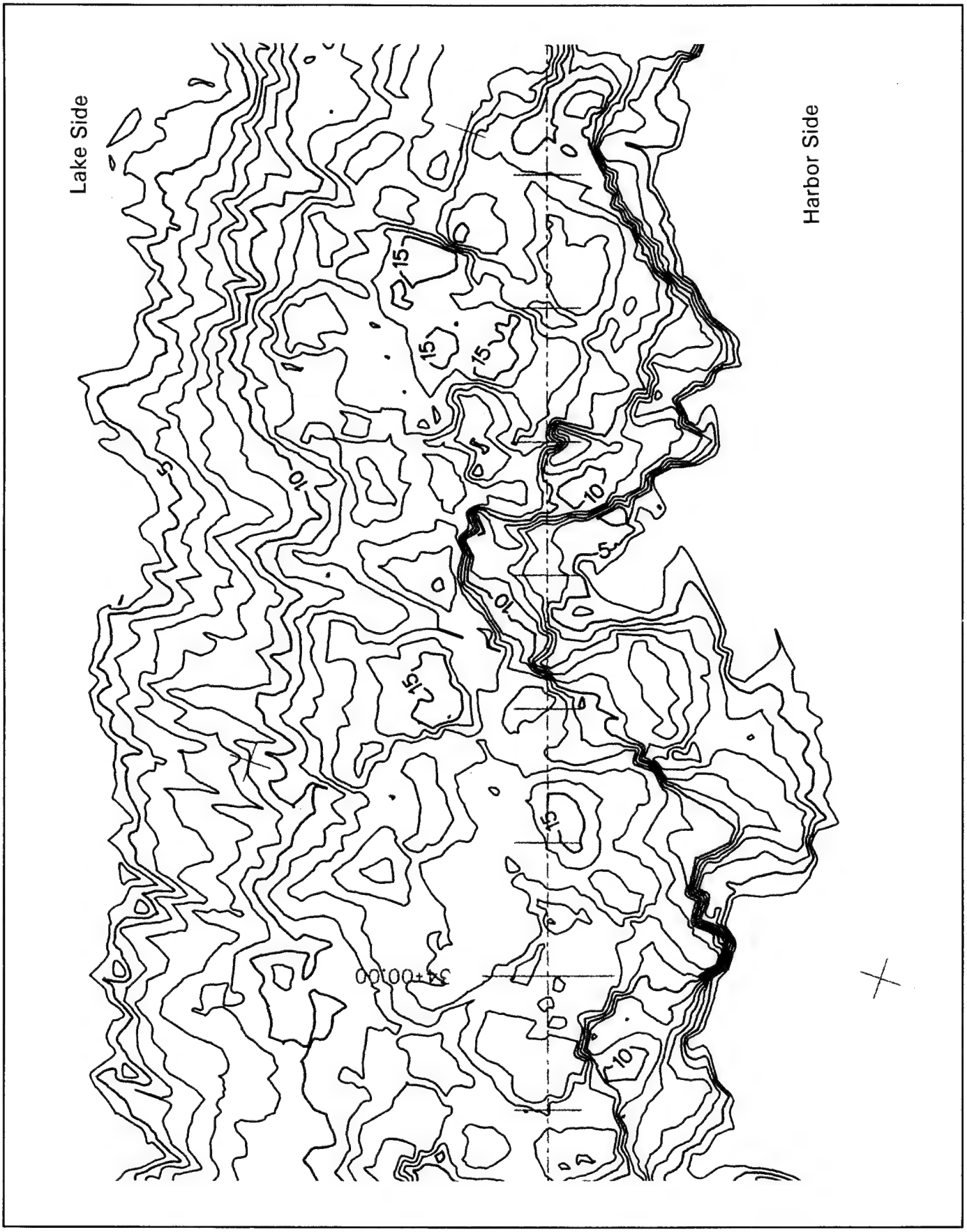


Figure A40. Topography of Burns Harbor North Breakwater, sta 33+30-34+15

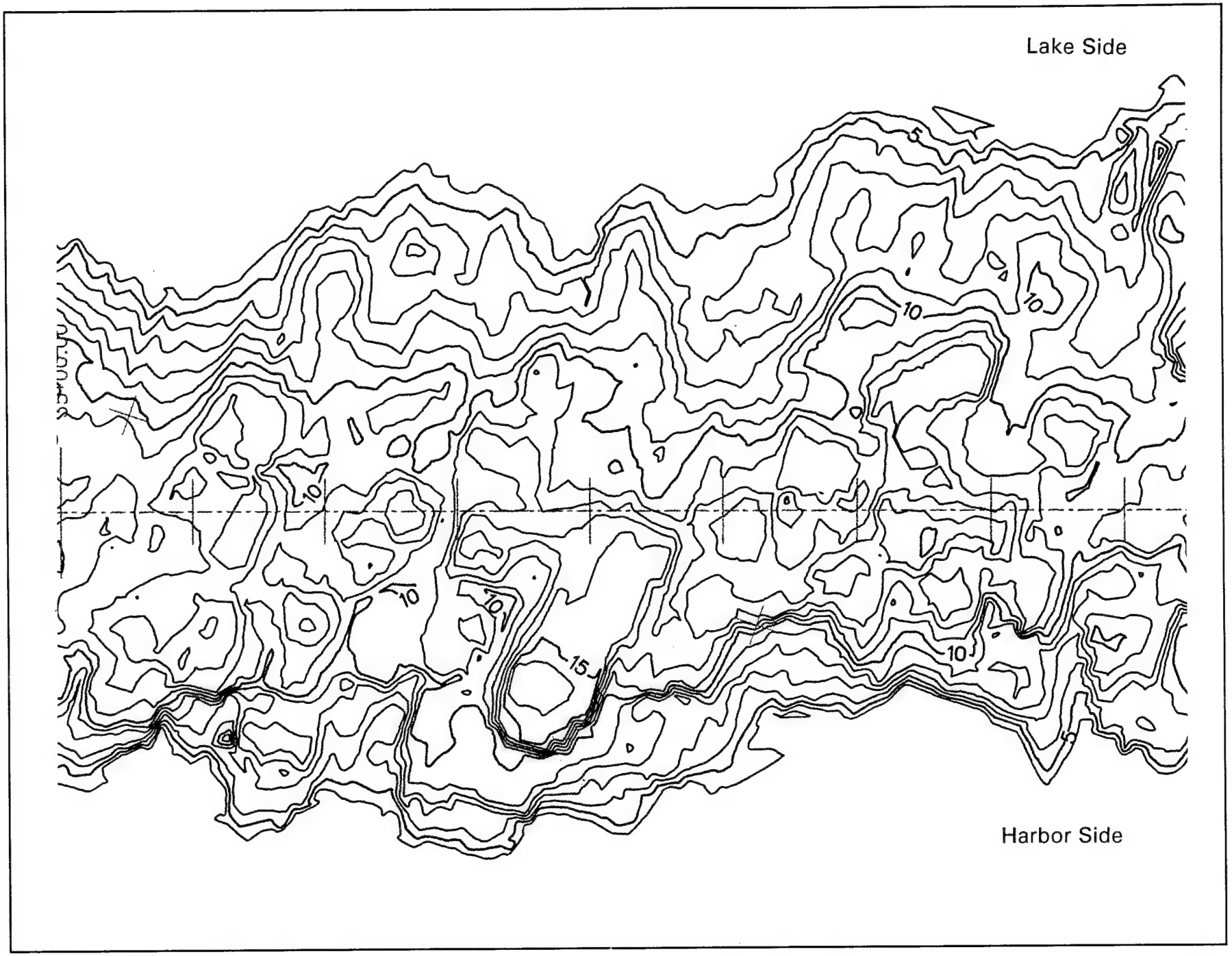


Figure A41. Topography of Burns Harbor North Breakwater, sta 34+15-35+00

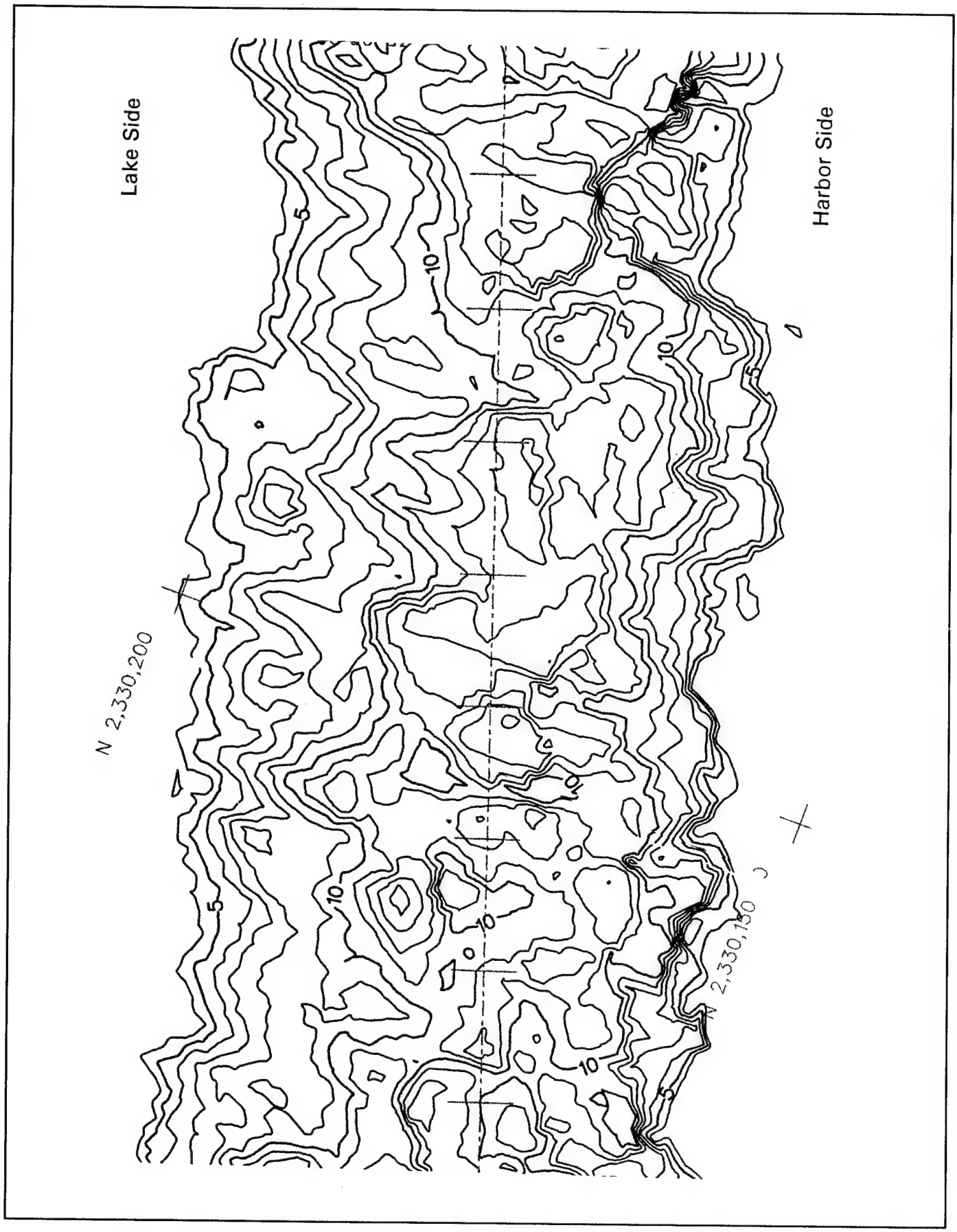


Figure A42. Topography of Burns Harbor North Breakwater, sta 35+00-35+85

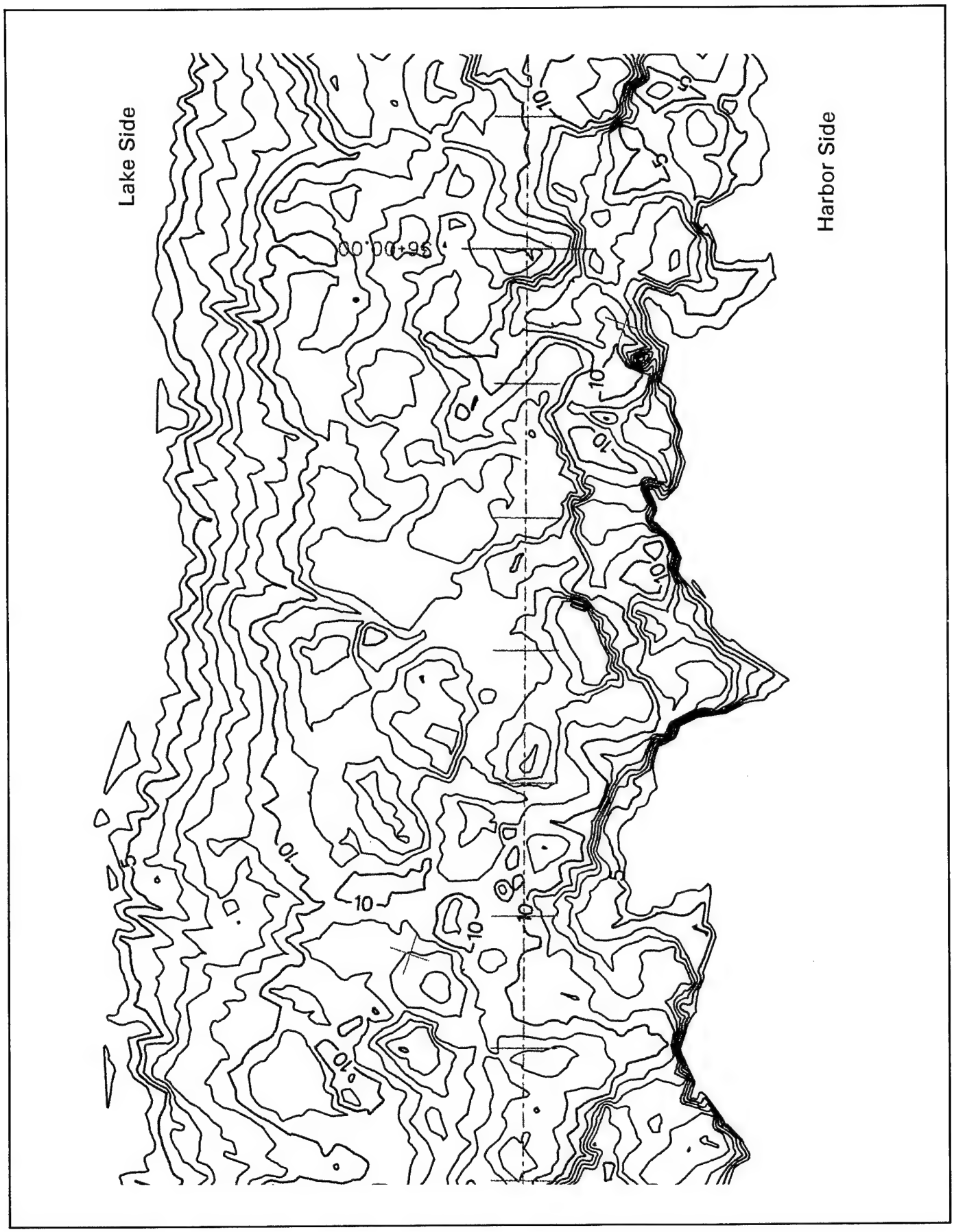


Figure A43. Topography of Burns Harbor North Breakwater, sta 35+85-36+70

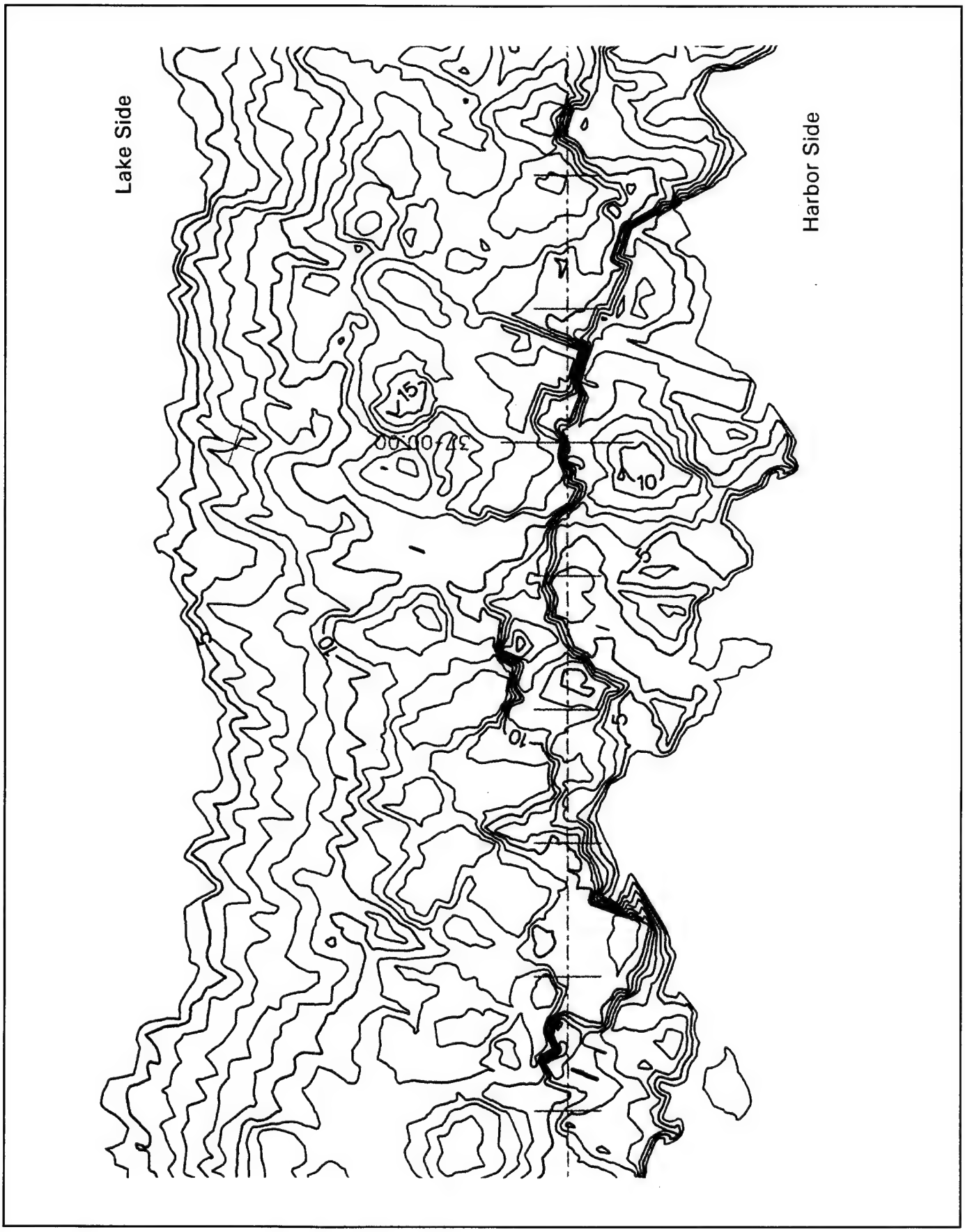


Figure A44. Topography of Burns Harbor North Breakwater, sta 36+70-37+55

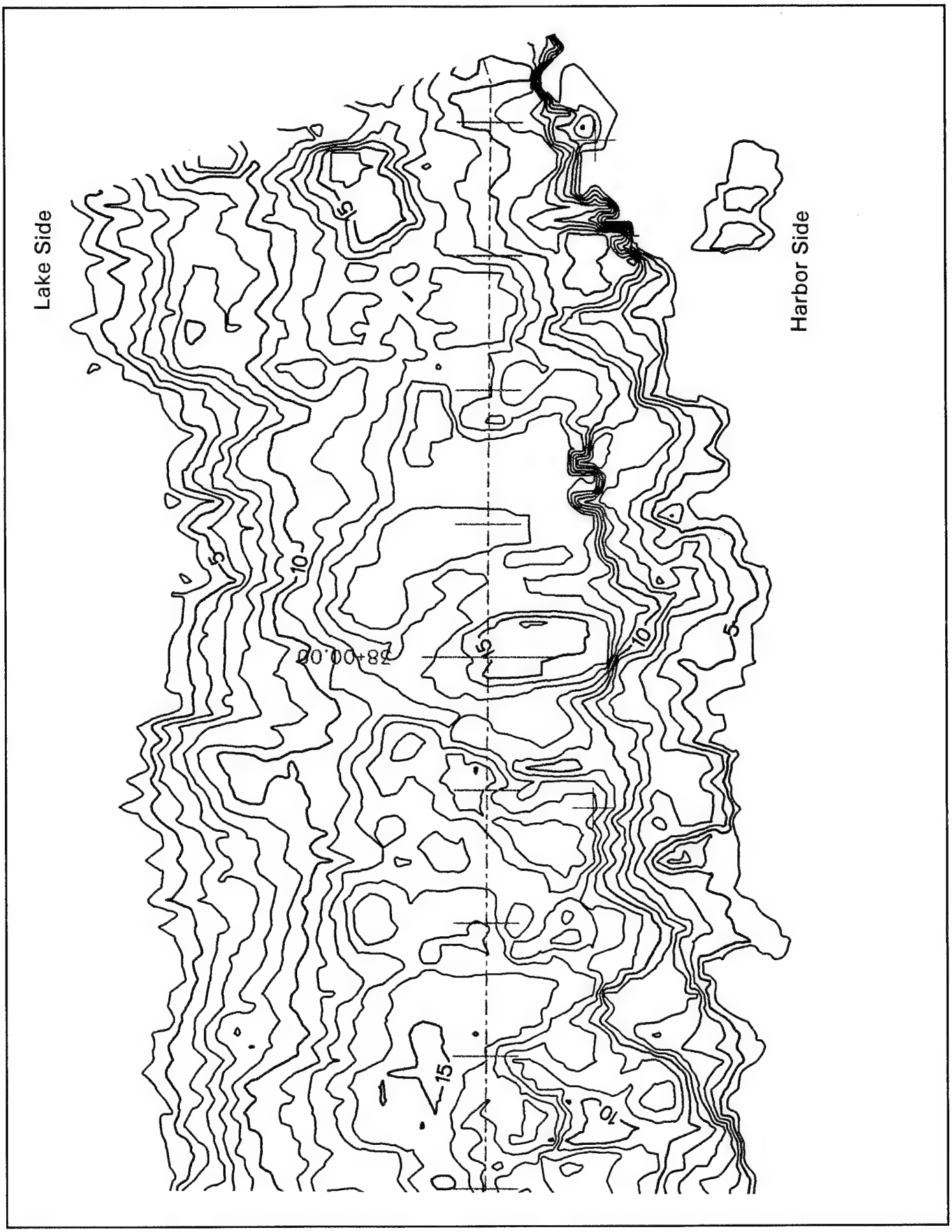


Figure A45. Topography of Burns Harbor North Breakwater, sta 37+55-38+40

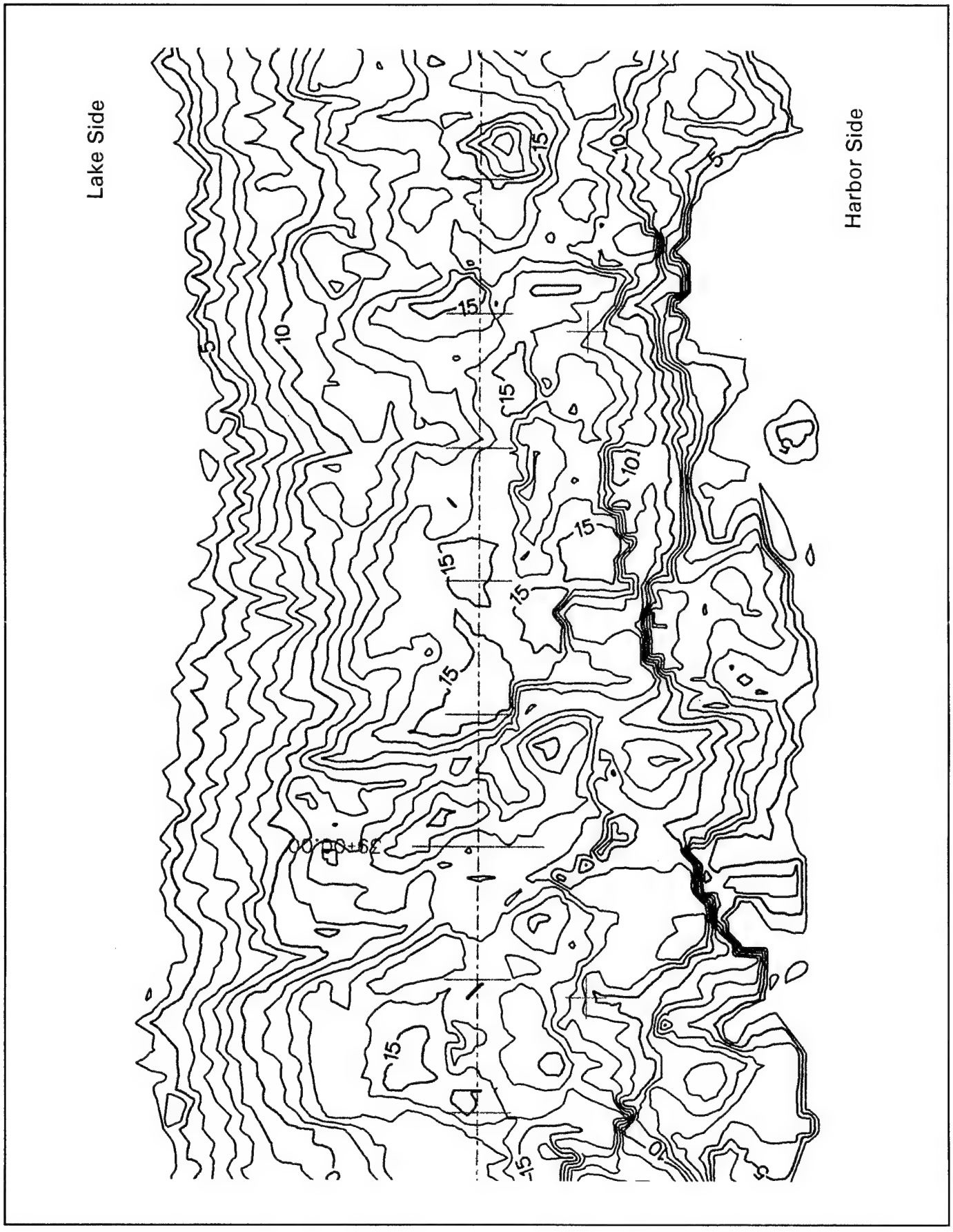


Figure A46. Topography of Burns Harbor North Breakwater, sta 38+40-39+25

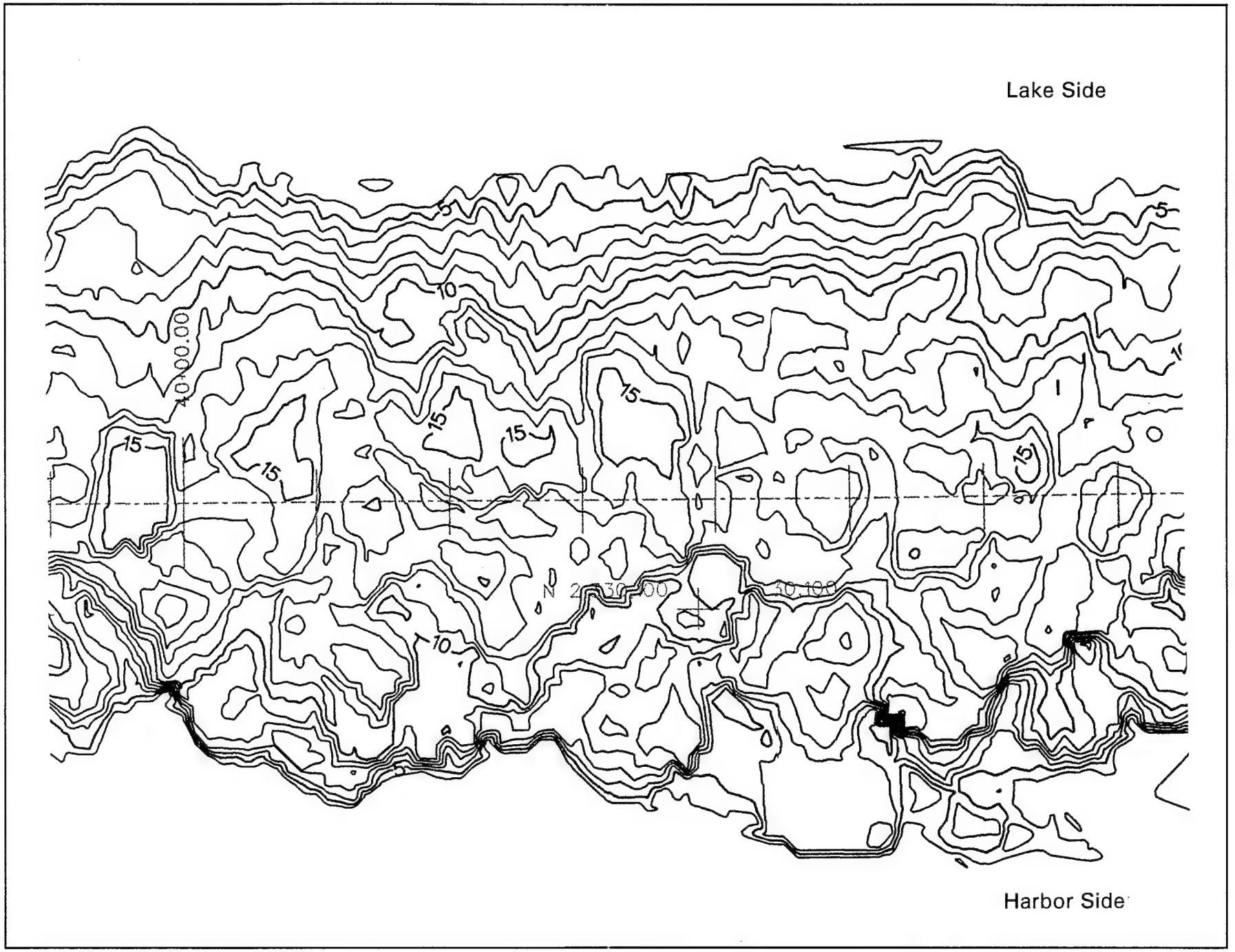


Figure A47. Topography of Burns Harbor North Breakwater, sta 39+25-40+10

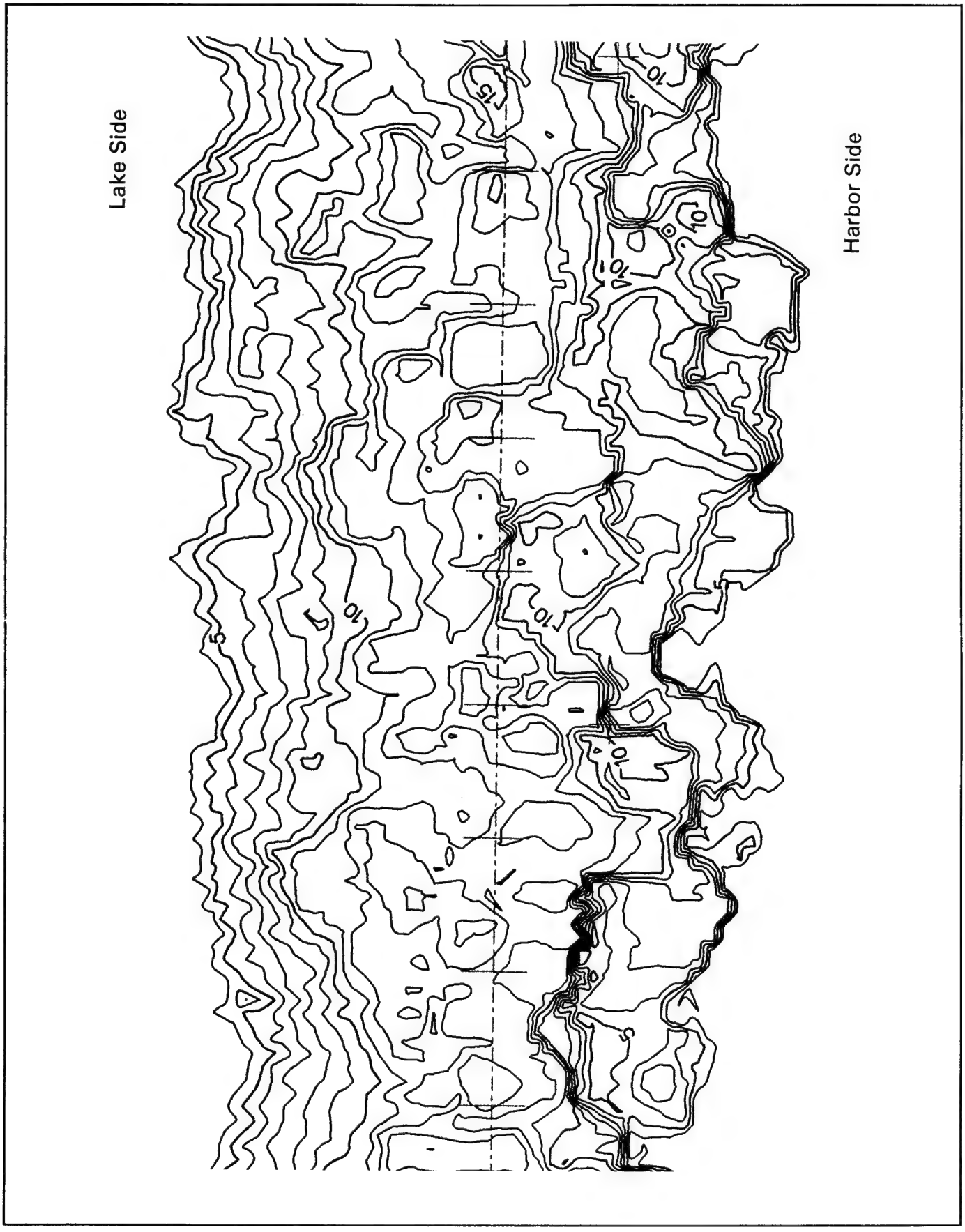


Figure A48. Topography of Burns Harbor North Breakwater, sta 40+10-40+95

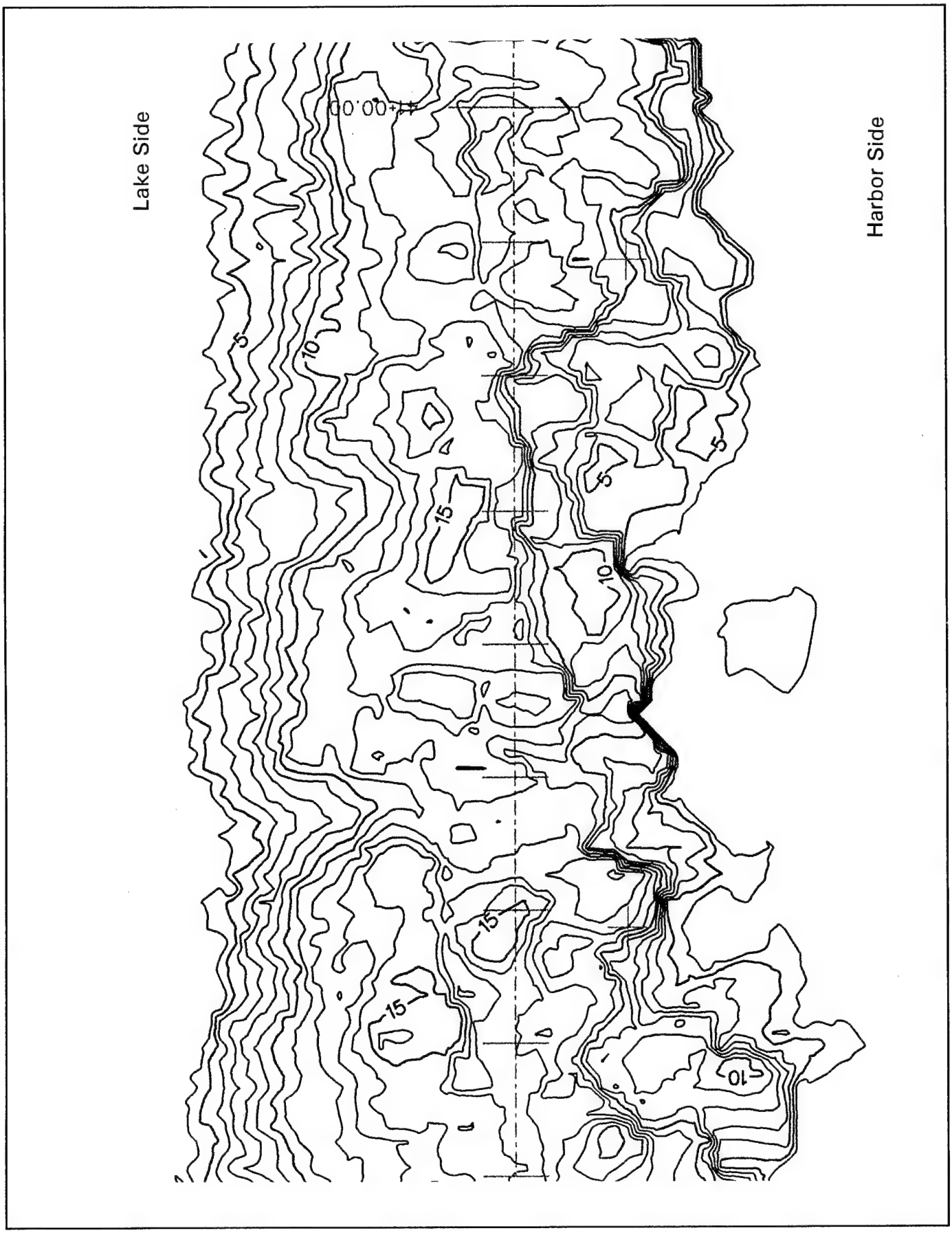


Figure A49. Topography of Burns Harbor North Breakwater, sta 40+95-41+80

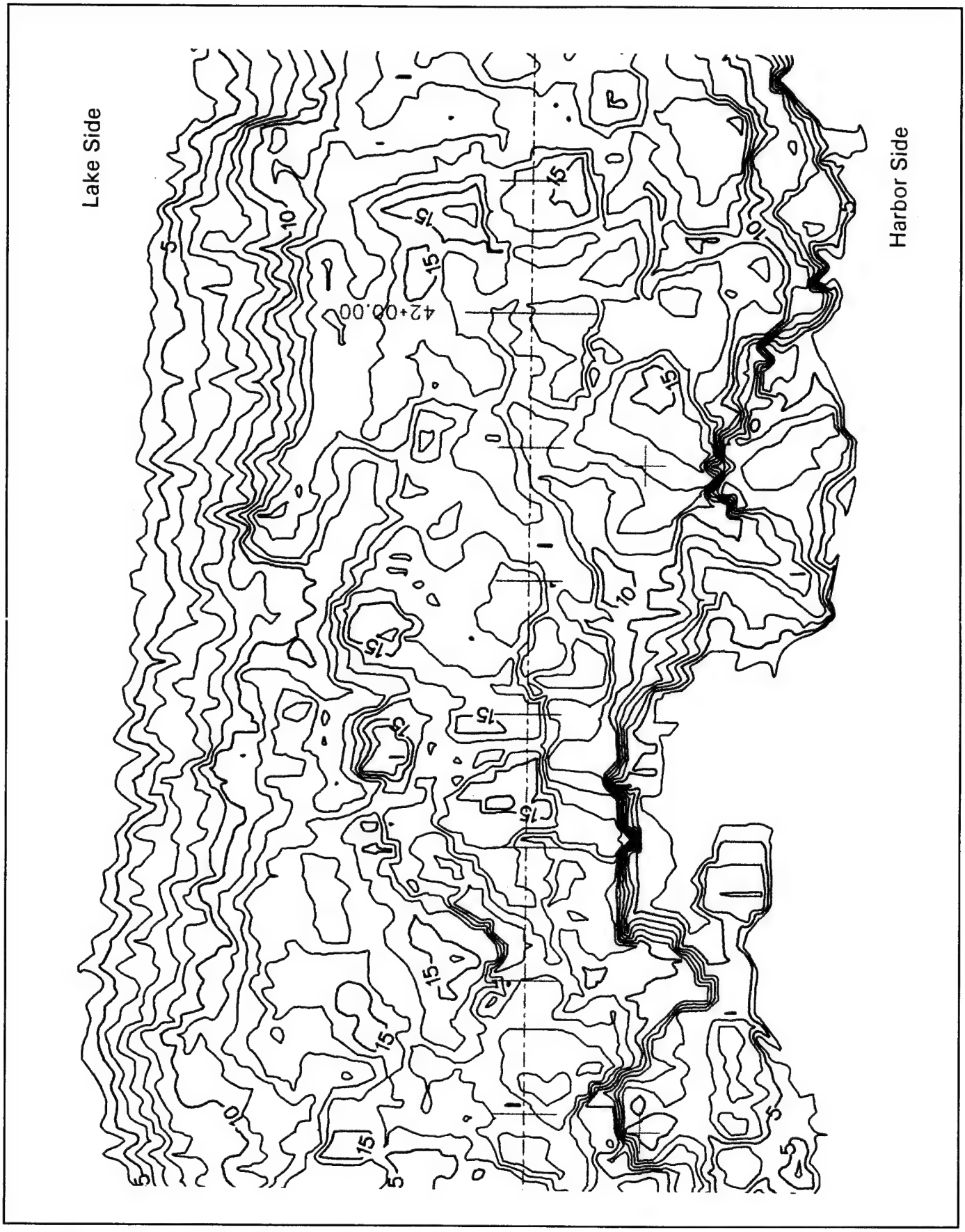


Figure A50. Topography of Burns Harbor North Breakwater, sta 41+80-42+66

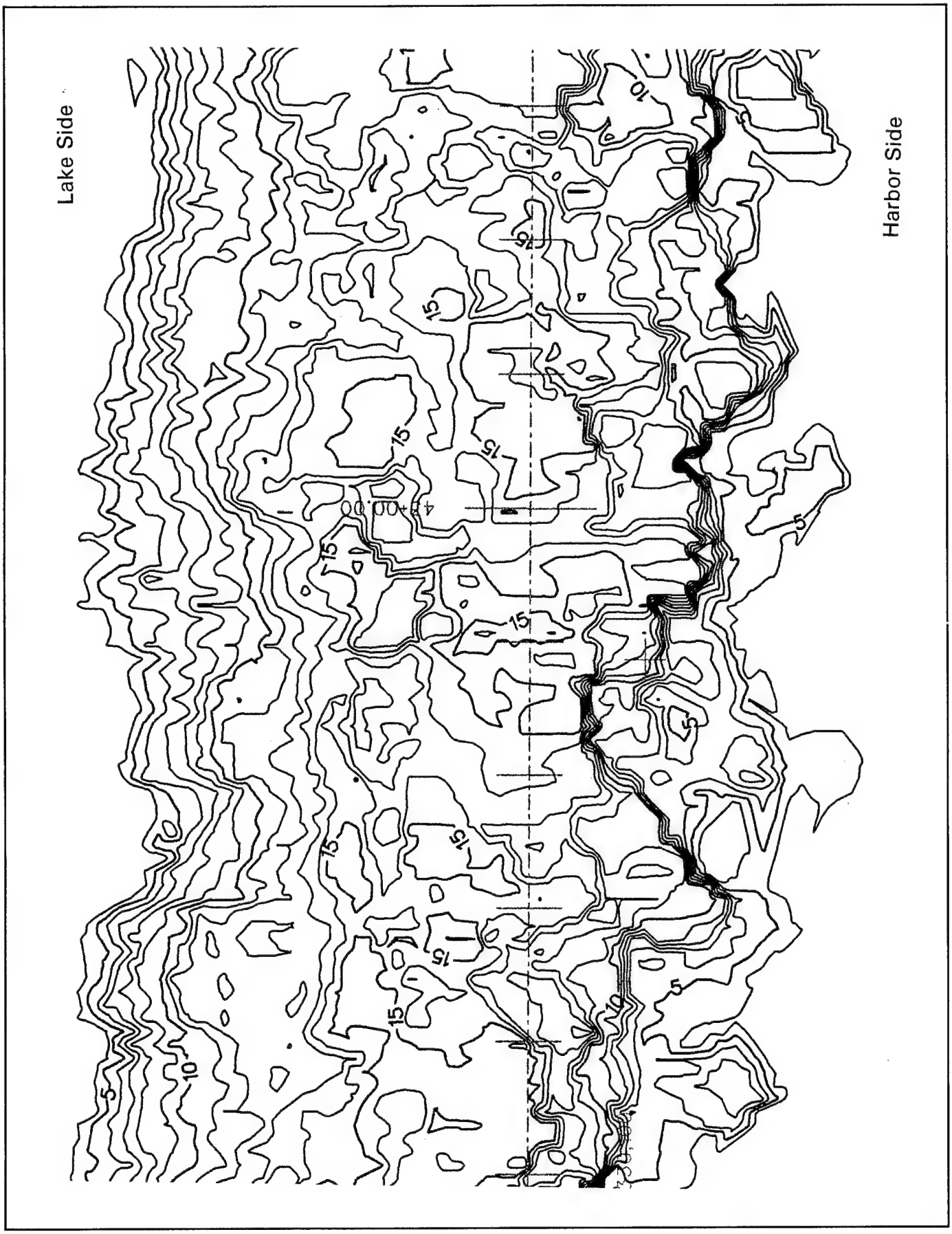


Figure A51. Topography of Burns Harbor North Breakwater, sta 42+66-43+51

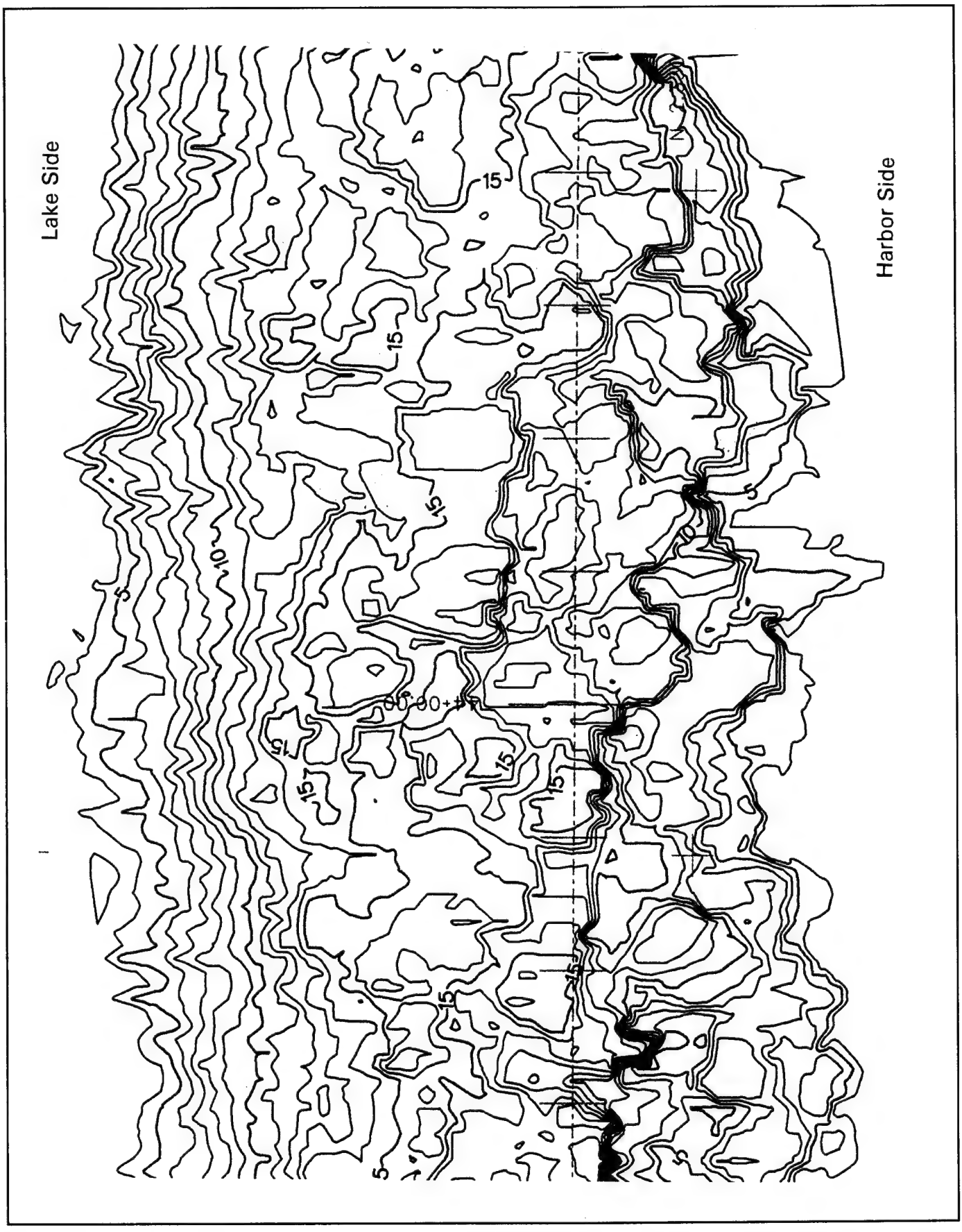


Figure A52. Topography of Burns Harbor North Breakwater, sta 43+51-44+36

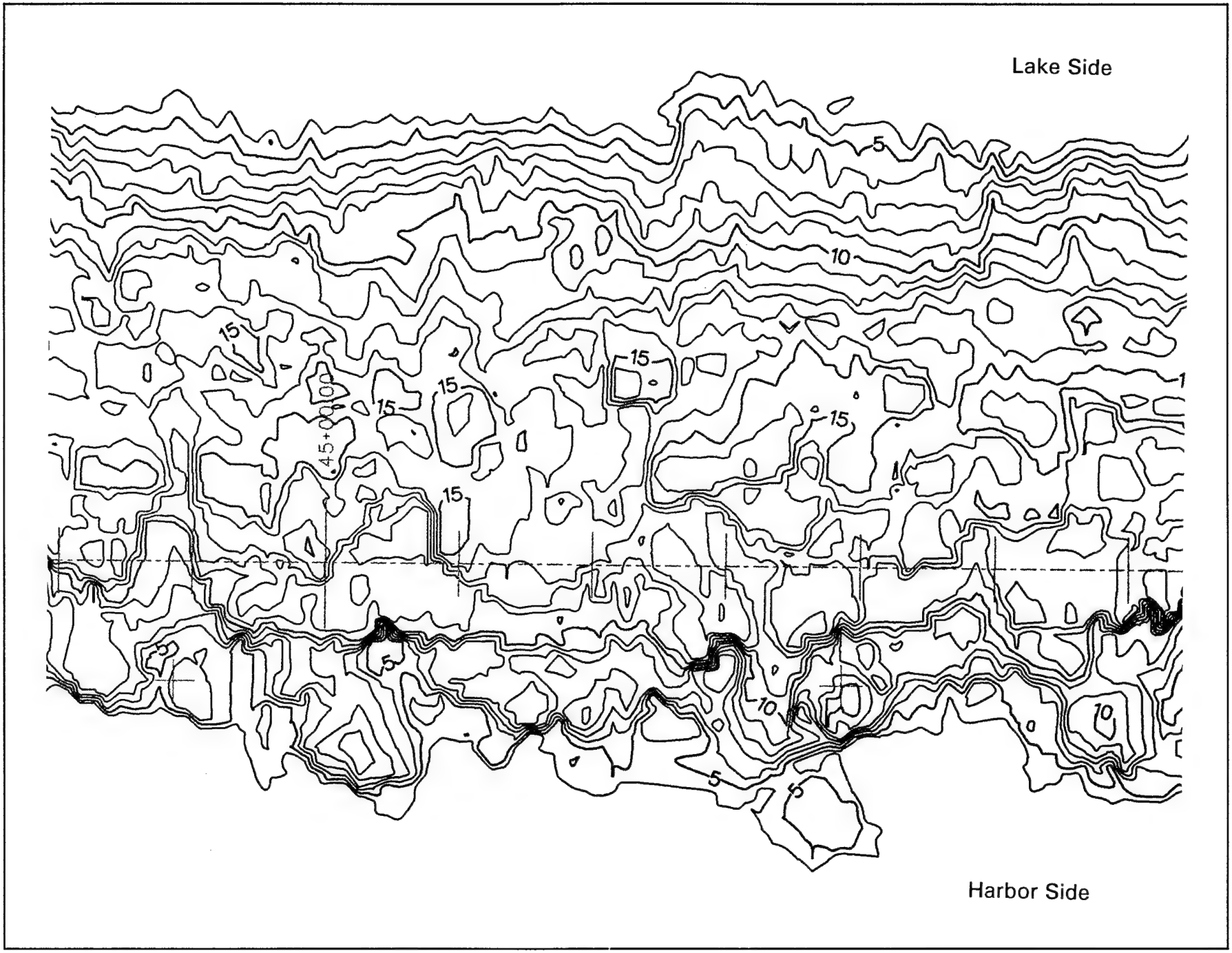


Figure A53. Topography of Burns Harbor North Breakwater, sta 44+36-45+21

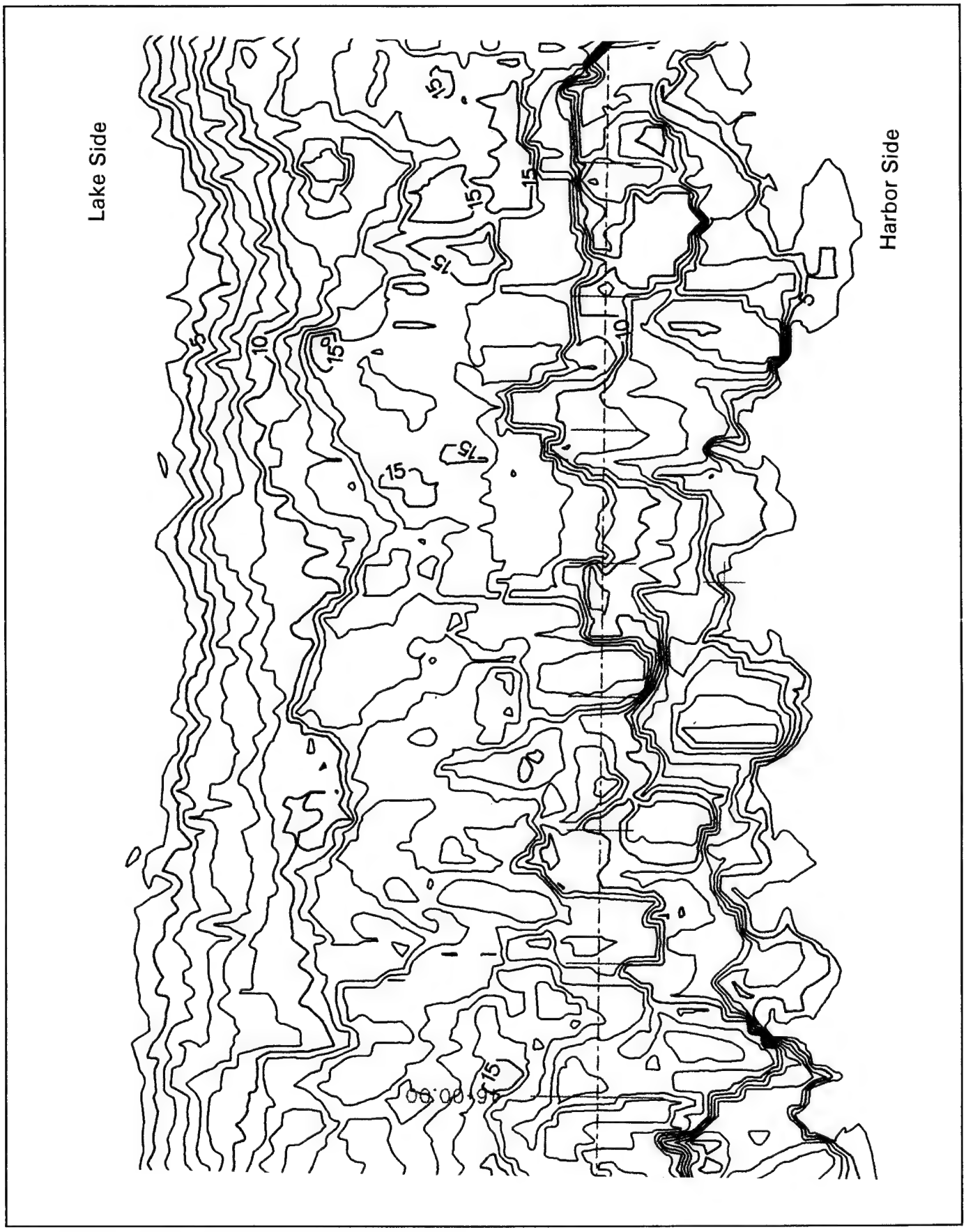


Figure A54. Topography of Burns Harbor North Breakwater, sta 45+21-46+06

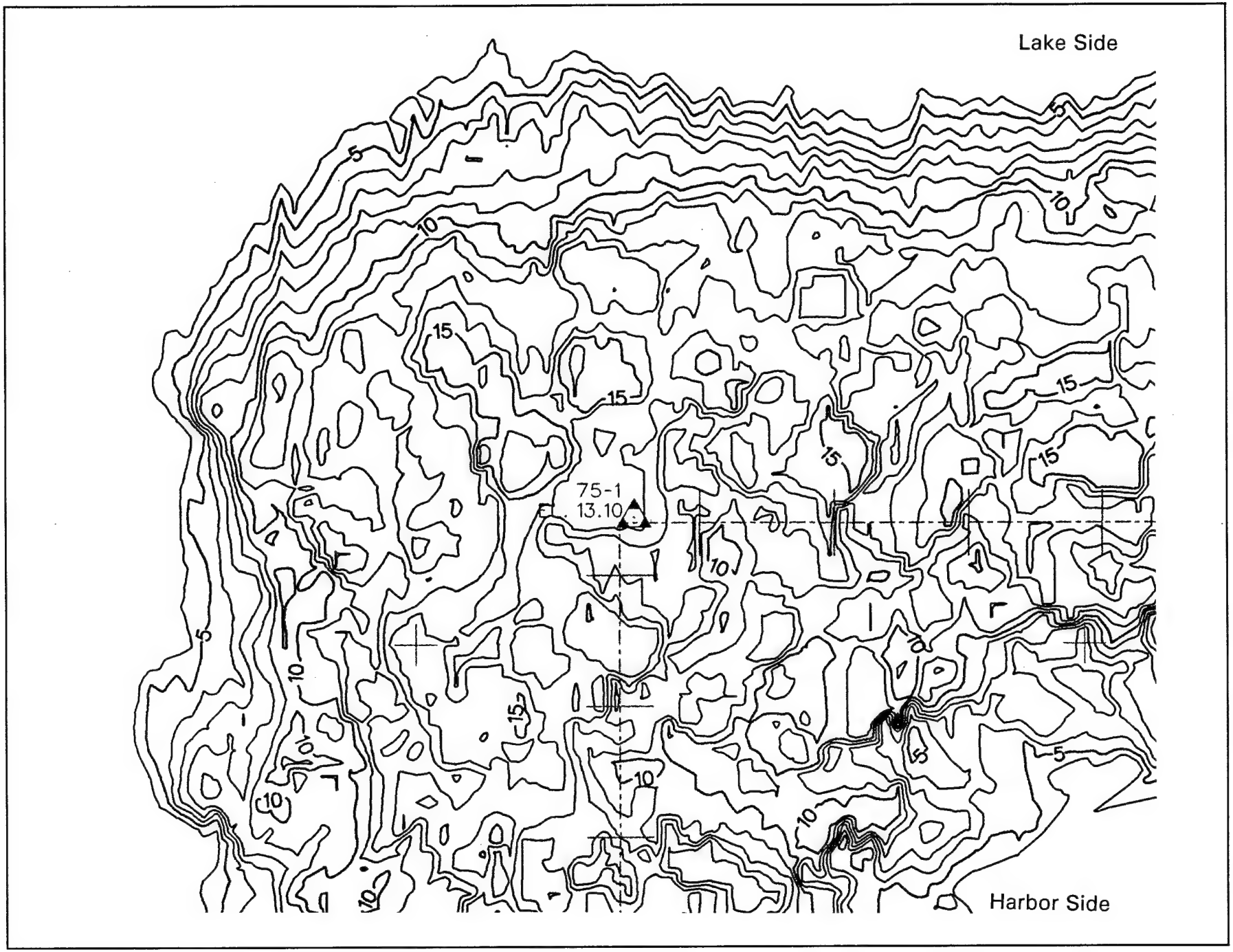


Figure A55. Topography of Burns Harbor North Breakwater, sta 46+06-46+40

Appendix B
Cross Sections of Burns Harbor North Breakwater

This appendix presents cross sections of the Burns Harbor North Breakwater. Cross sections were developed using the digital terrain model (DTM) grid as stated in the main text of this report. They were obtained at 0.3-rad (15-deg) intervals around the head of the breakwater and 15.2-m (50-ft) intervals along the trunk as shown in Figure 10 in the main text of this report. Elevations shown are in feet referred to low water datum (lwd). To convert them to meters, multiply by 0.3048. Distances from the baseline also are shown in feet and may be converted to meters using the same factor. The baseline established was the approximate center line of the breakwater. Negative distances are measured relative to the harbor side of the baseline and positive distances are measured relative to the lake side of the baseline.

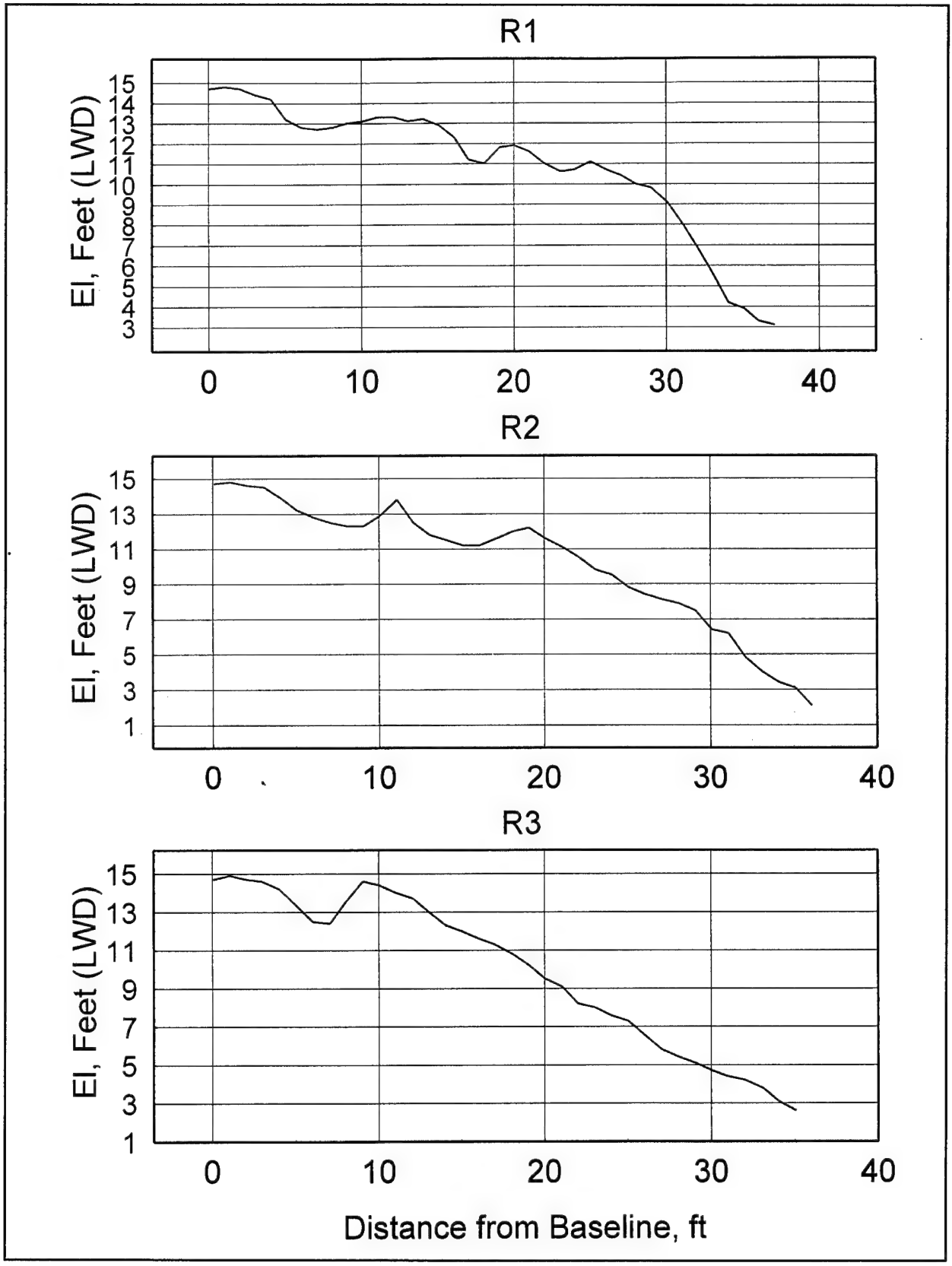


Figure B1. Cross sections of Burns Harbor North Breakwater, sta R1, R2, and R3

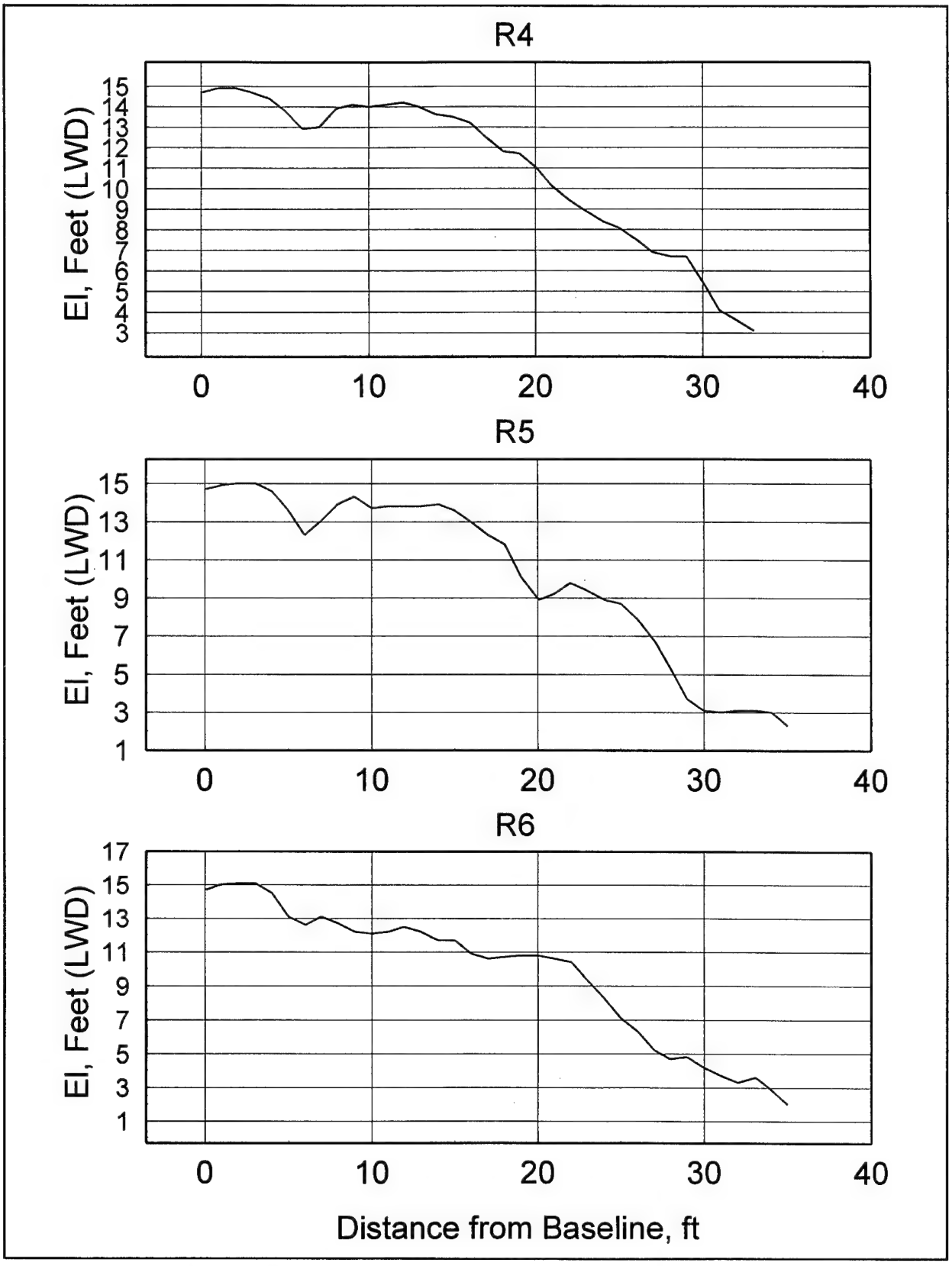


Figure B2. Cross sections of Burns Harbor North Breakwater, sta R4, R5, and R6

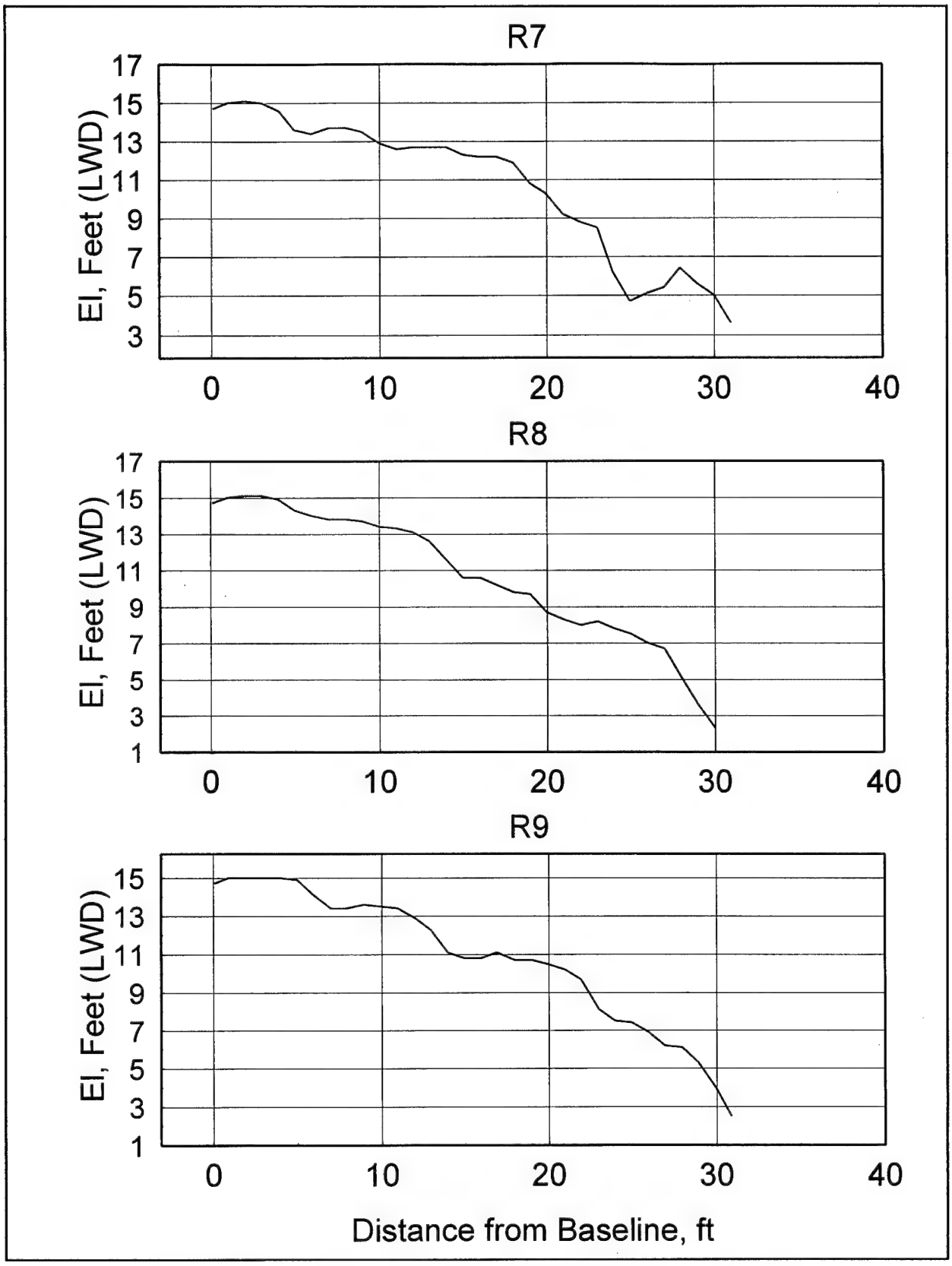


Figure B3. Cross sections of Burns Harbor North Breakwater, sta R7, R8, and R9

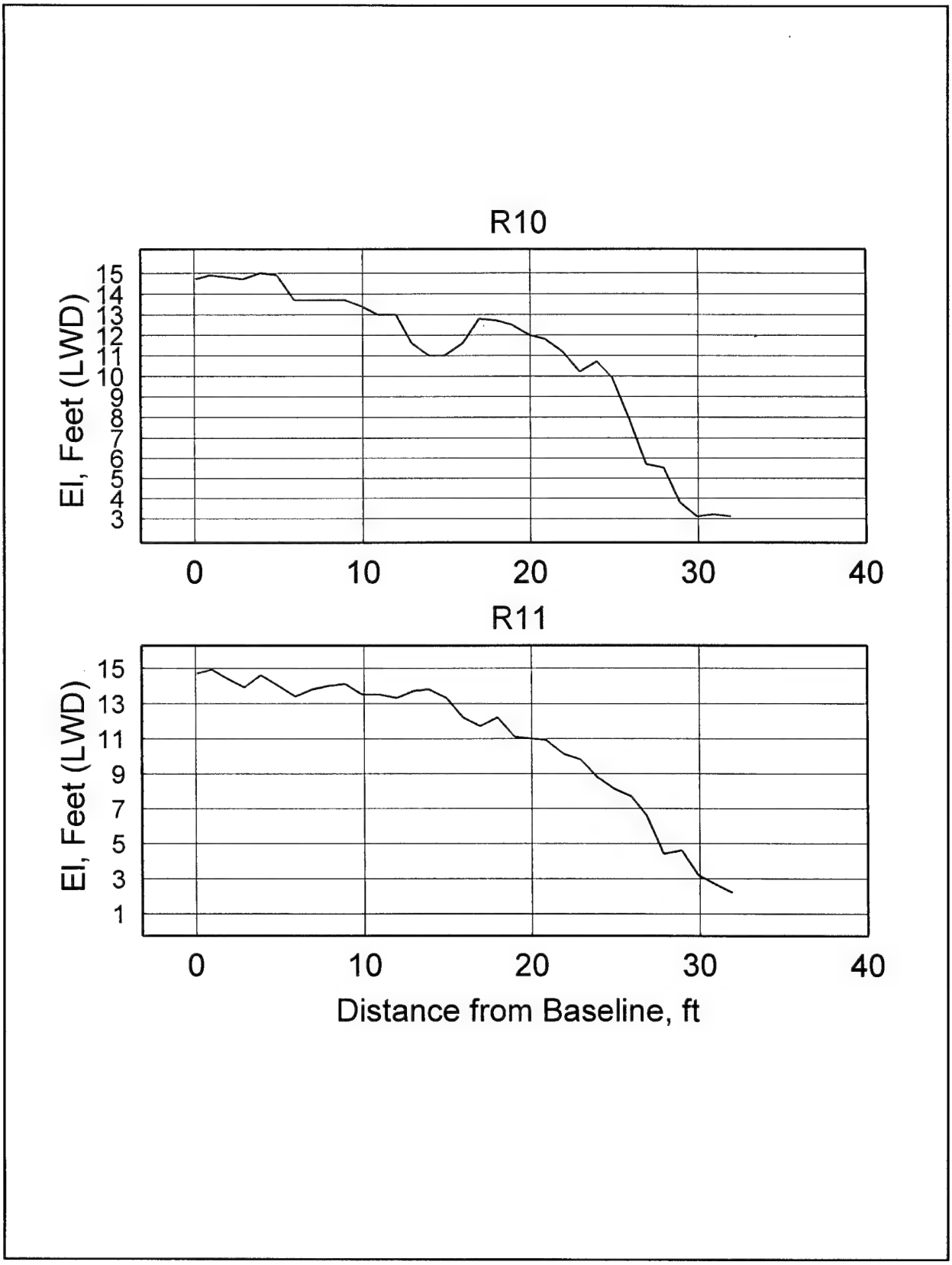


Figure B4. Cross sections of Burns Harbor North Breakwater, sta R10 and R11

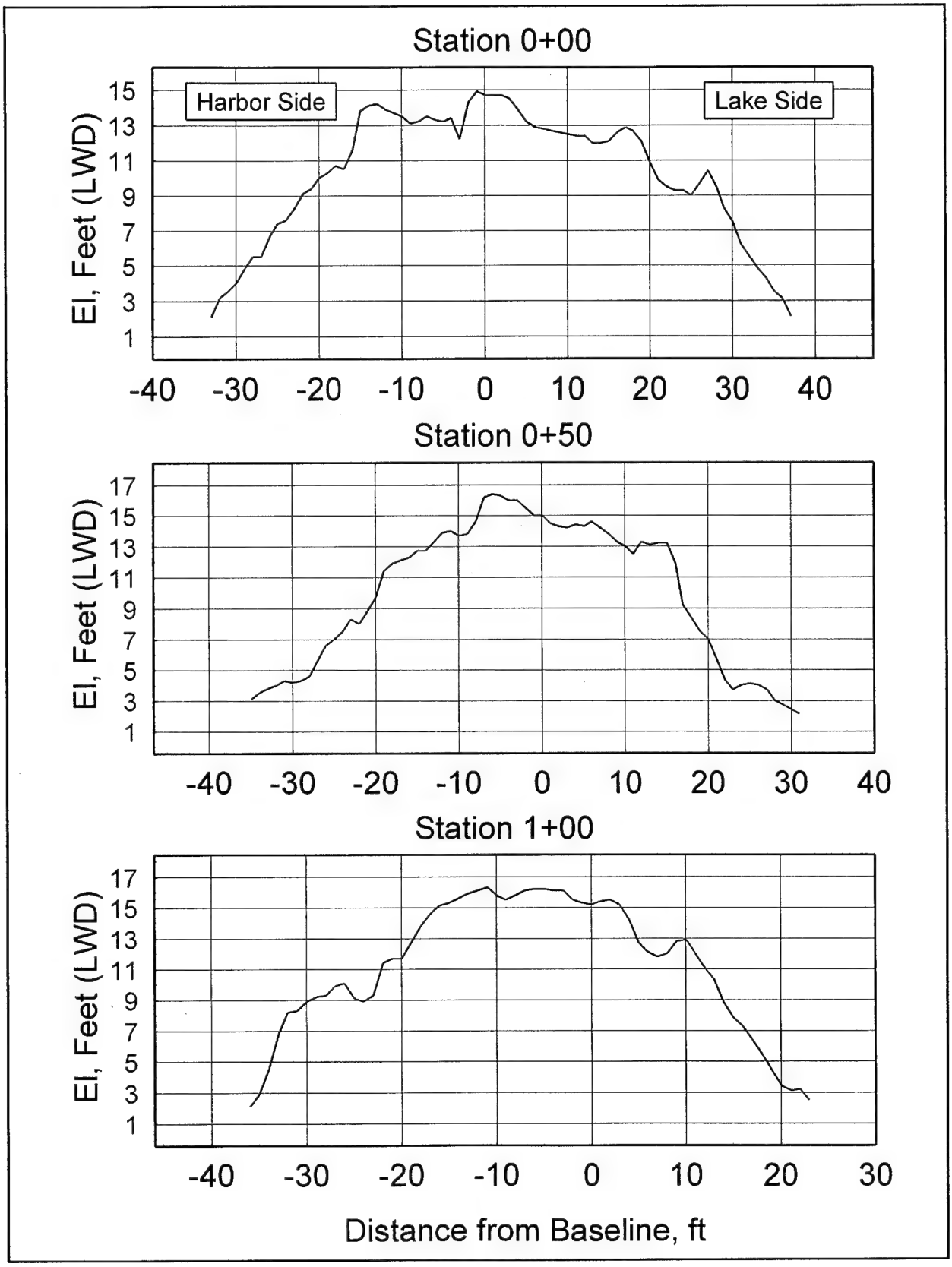


Figure B5. Cross sections of Burns Harbor North Breakwater, sta 0+00,0+50, and 1+00

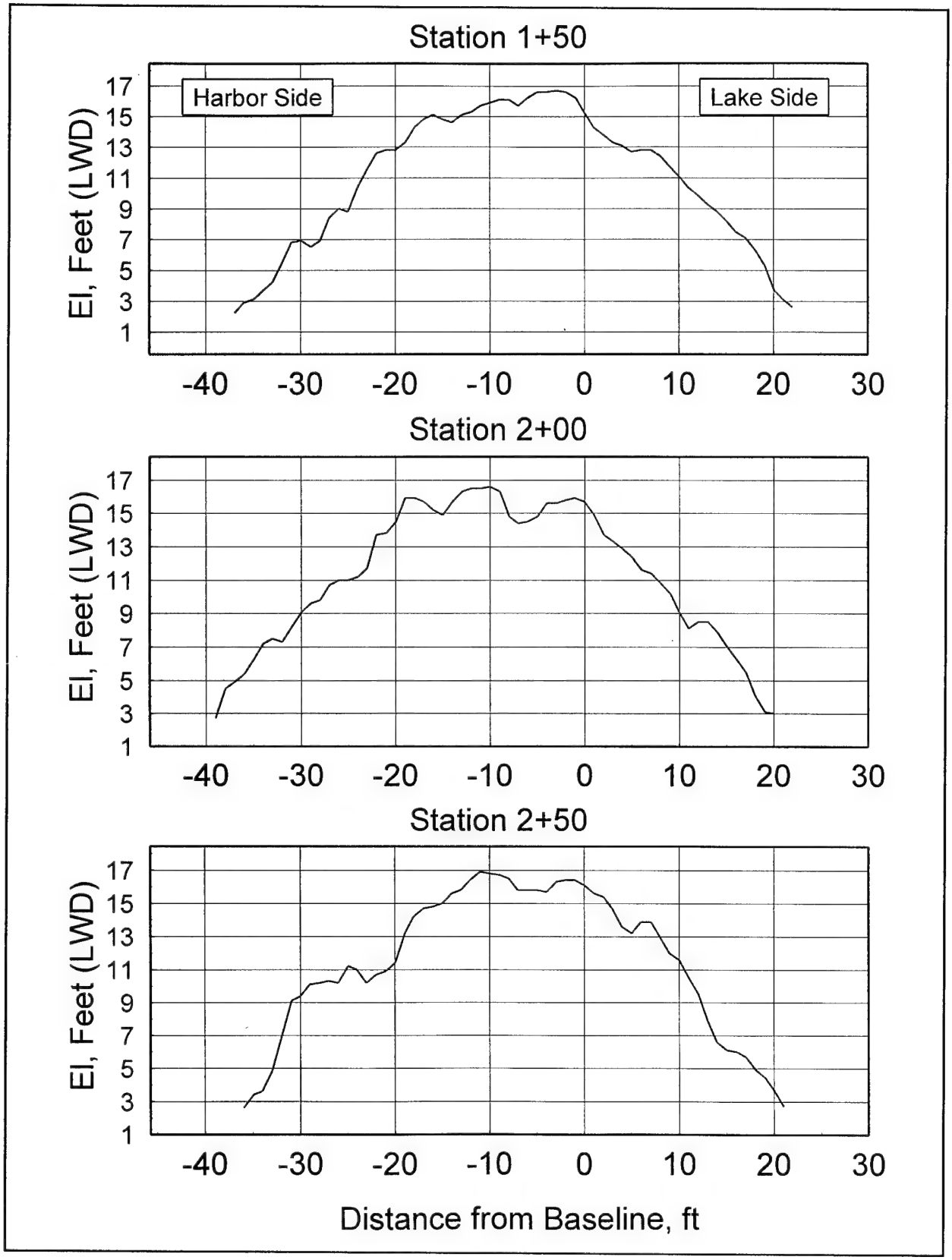


Figure B6. Cross sections of Burns Harbor North Breakwater, sta 1+50, 2+00, and 2+50

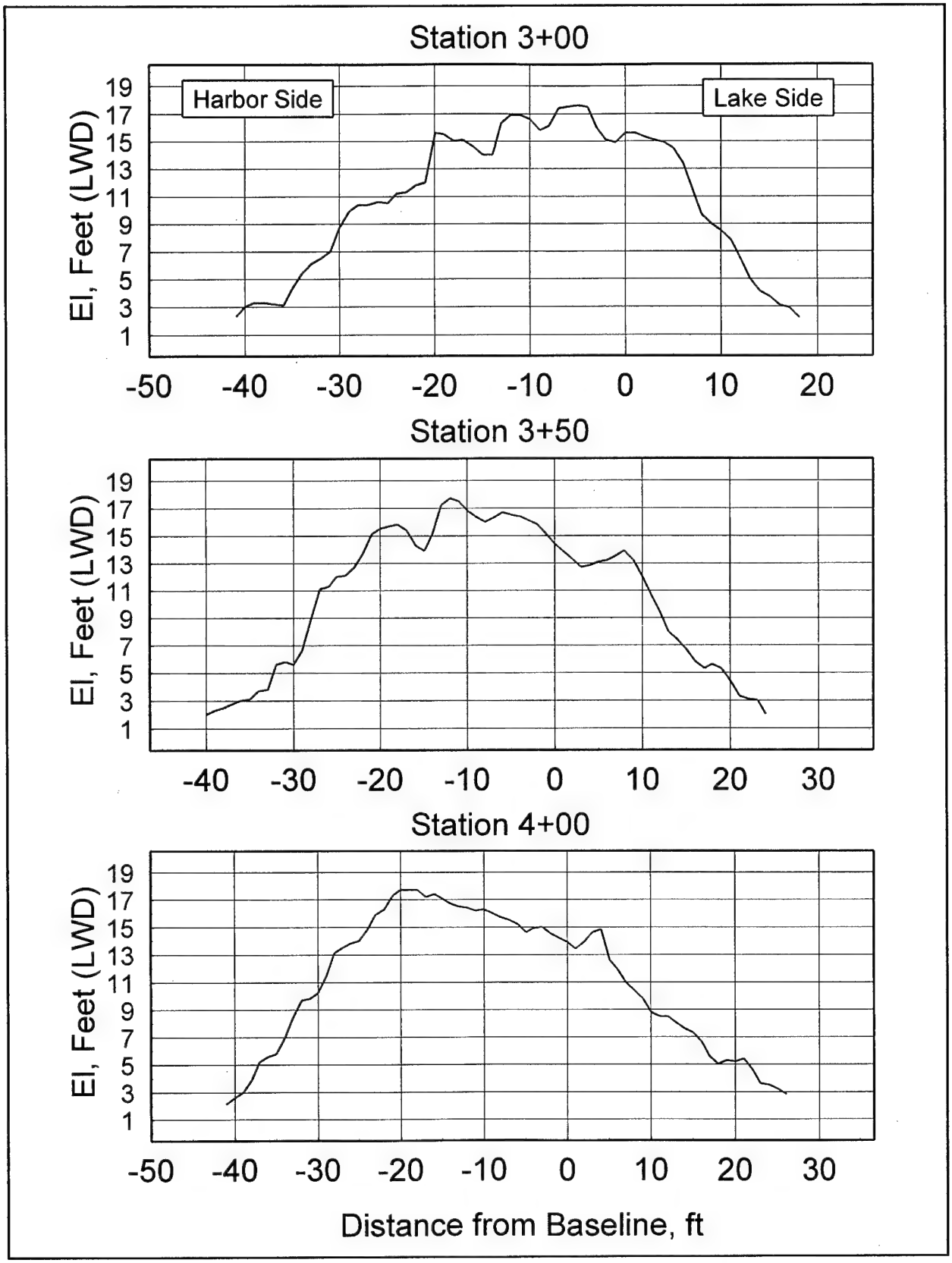


Figure B7. Cross sections of Burns Harbor North Breakwater, sta 3+00, 3+50, and 4+00

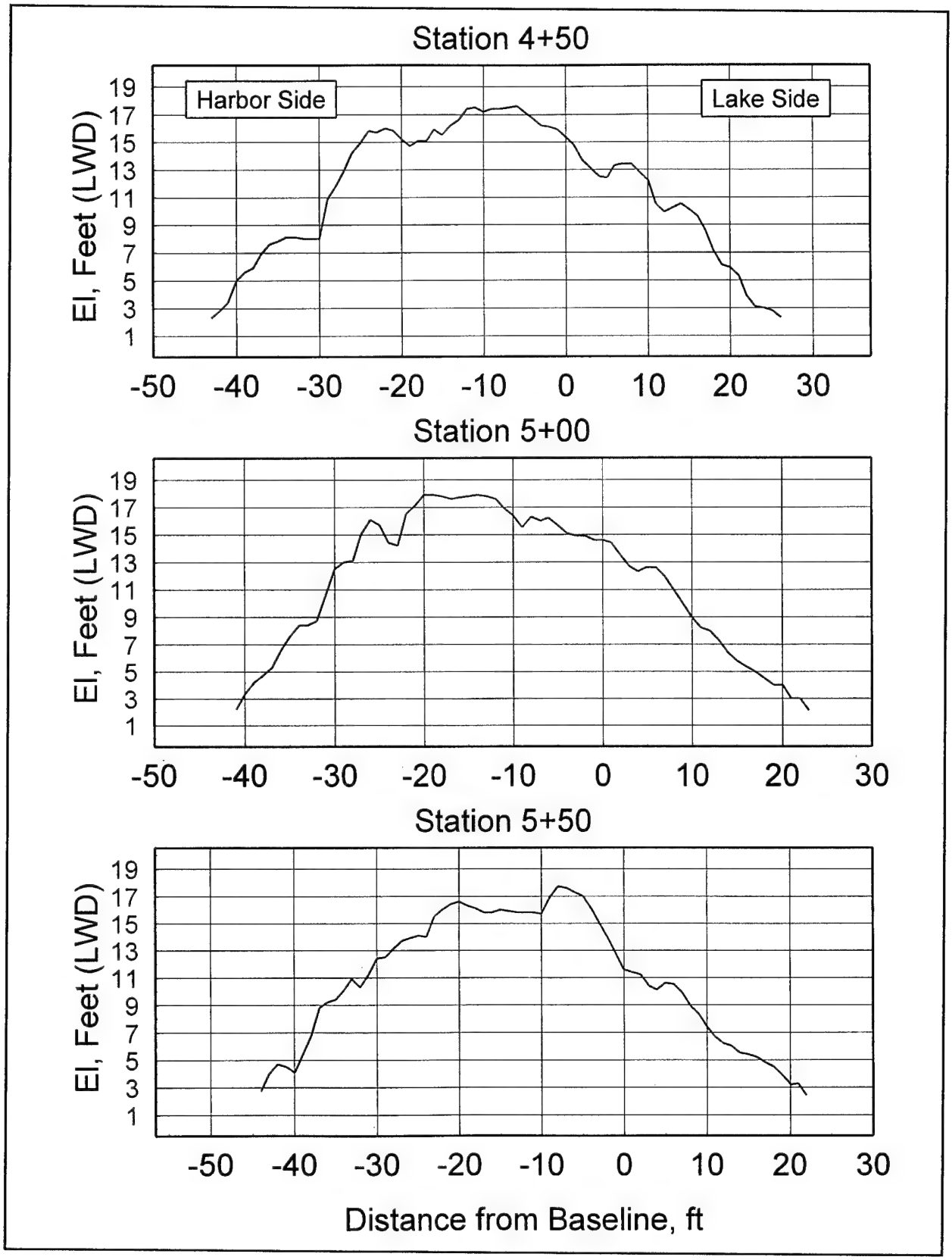


Figure B8. Cross sections of Burns Harbor North Breakwater, sta 4+50, 5+00, and 5+50

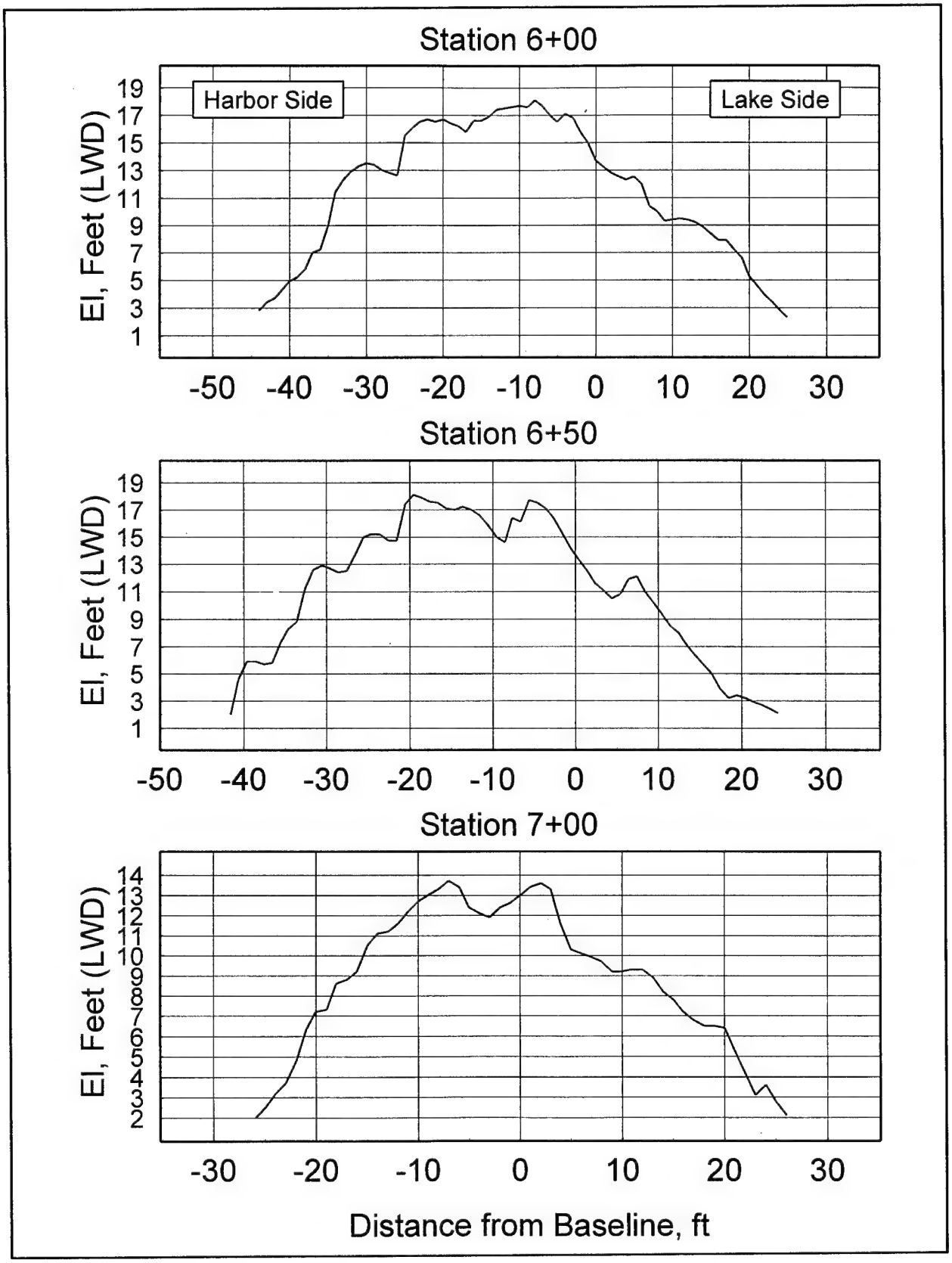


Figure B9. Cross sections of Burns Harbor North Breakwater, sta 6+00, 6+50, and 7+00

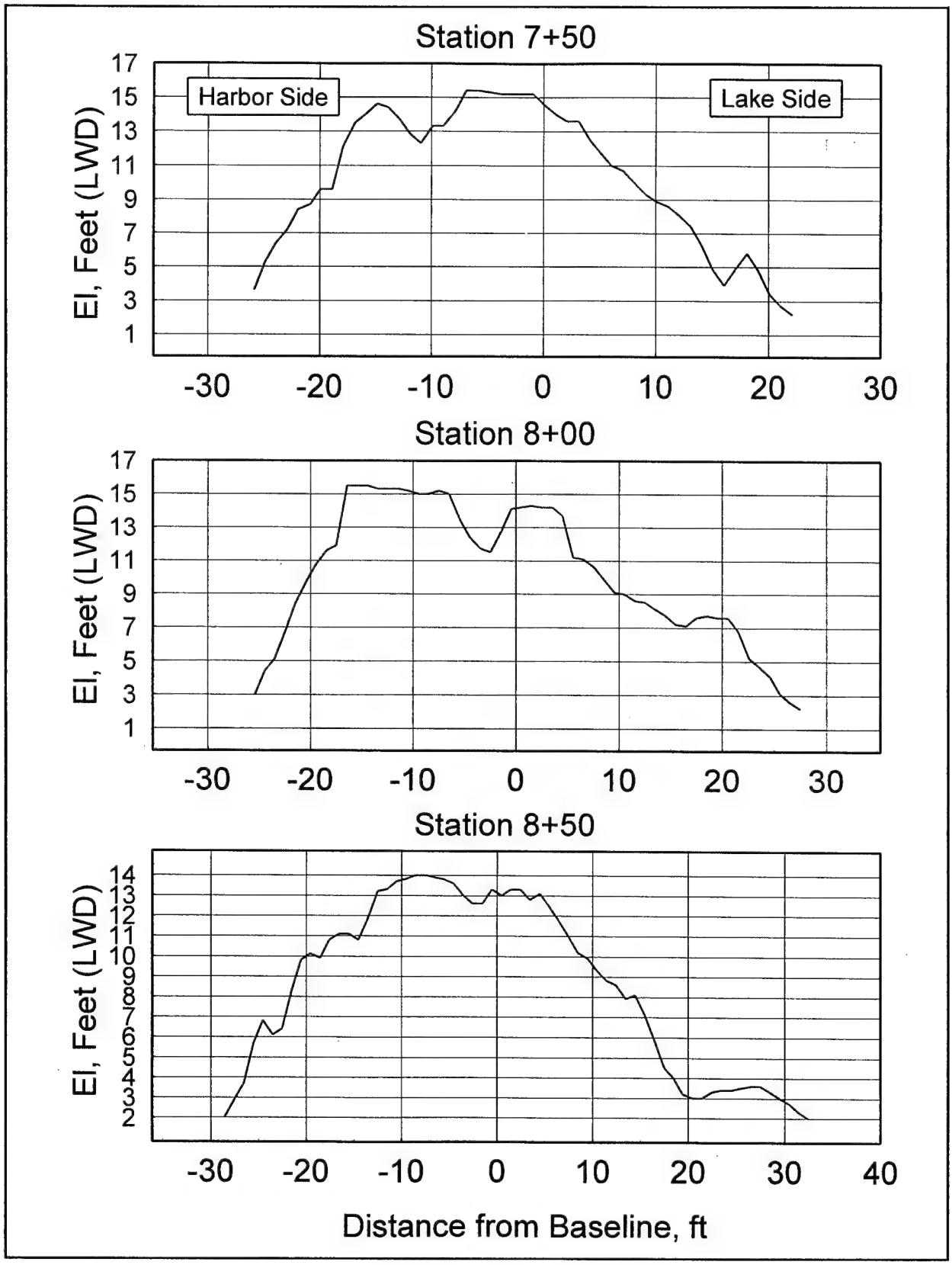


Figure B10. Cross sections of Burns Harbor North Breakwater, sta 7+50, 8+00, and 8+50

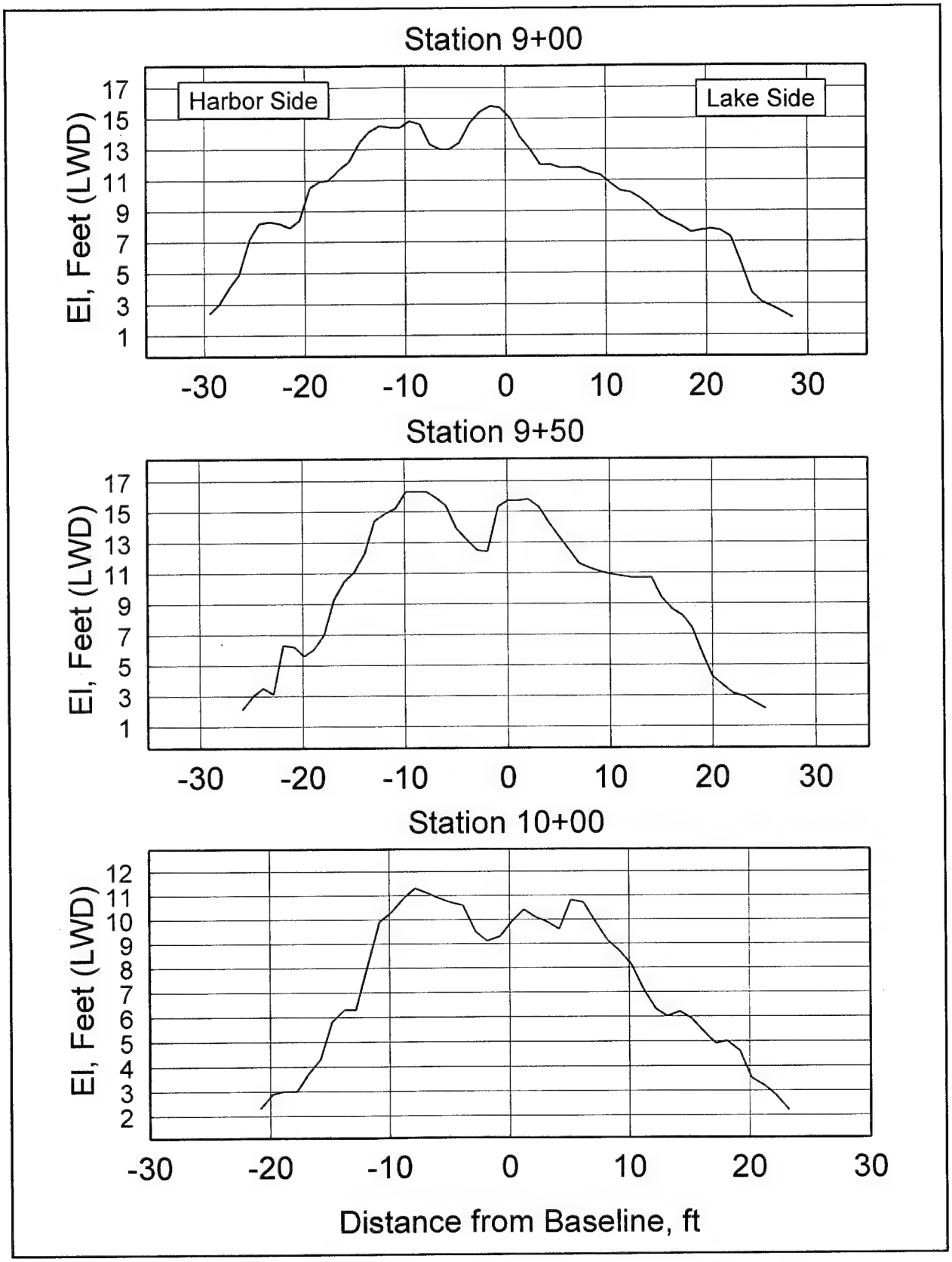


Figure B11. Cross sections of Burns Harbor North Breakwater, sta 9+00, 9+50, and 10+00

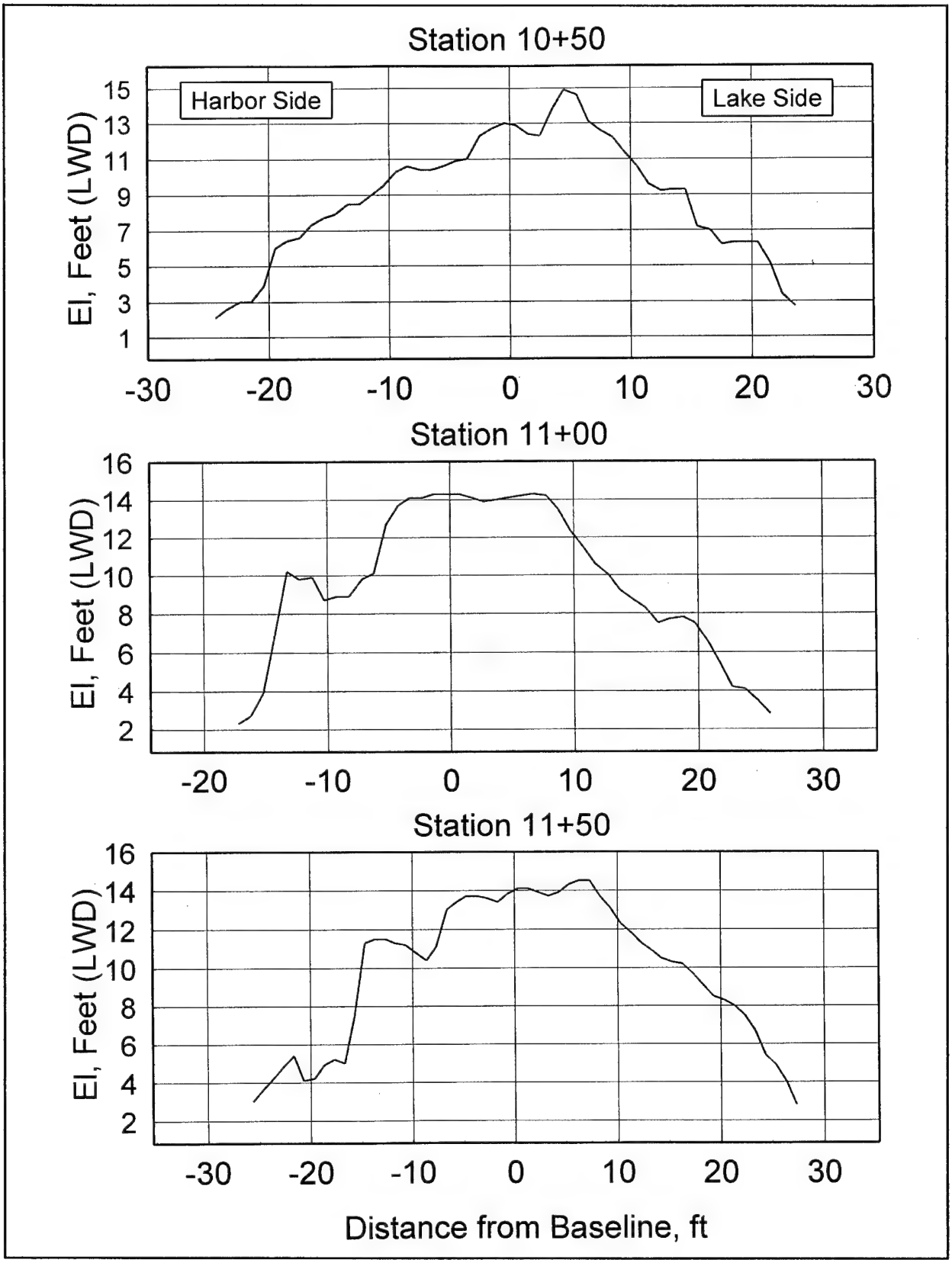


Figure B12. Cross sections of Burns Harbor North Breakwater, sta 10+50, 11+00, and 11+50

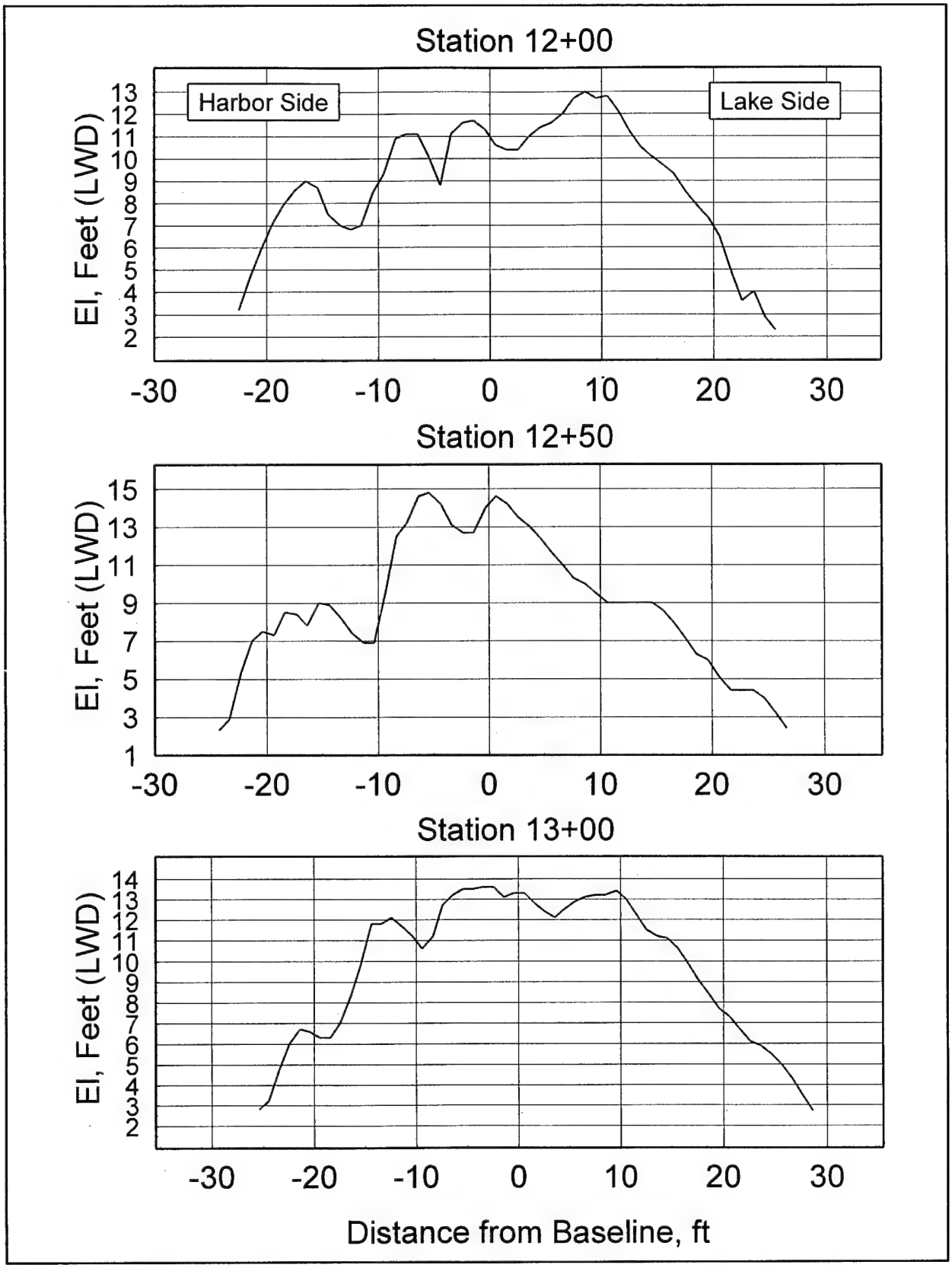


Figure B13. Cross sections of Burns Harbor North Breakwater, sta 12+00, 12+50, and 13+00

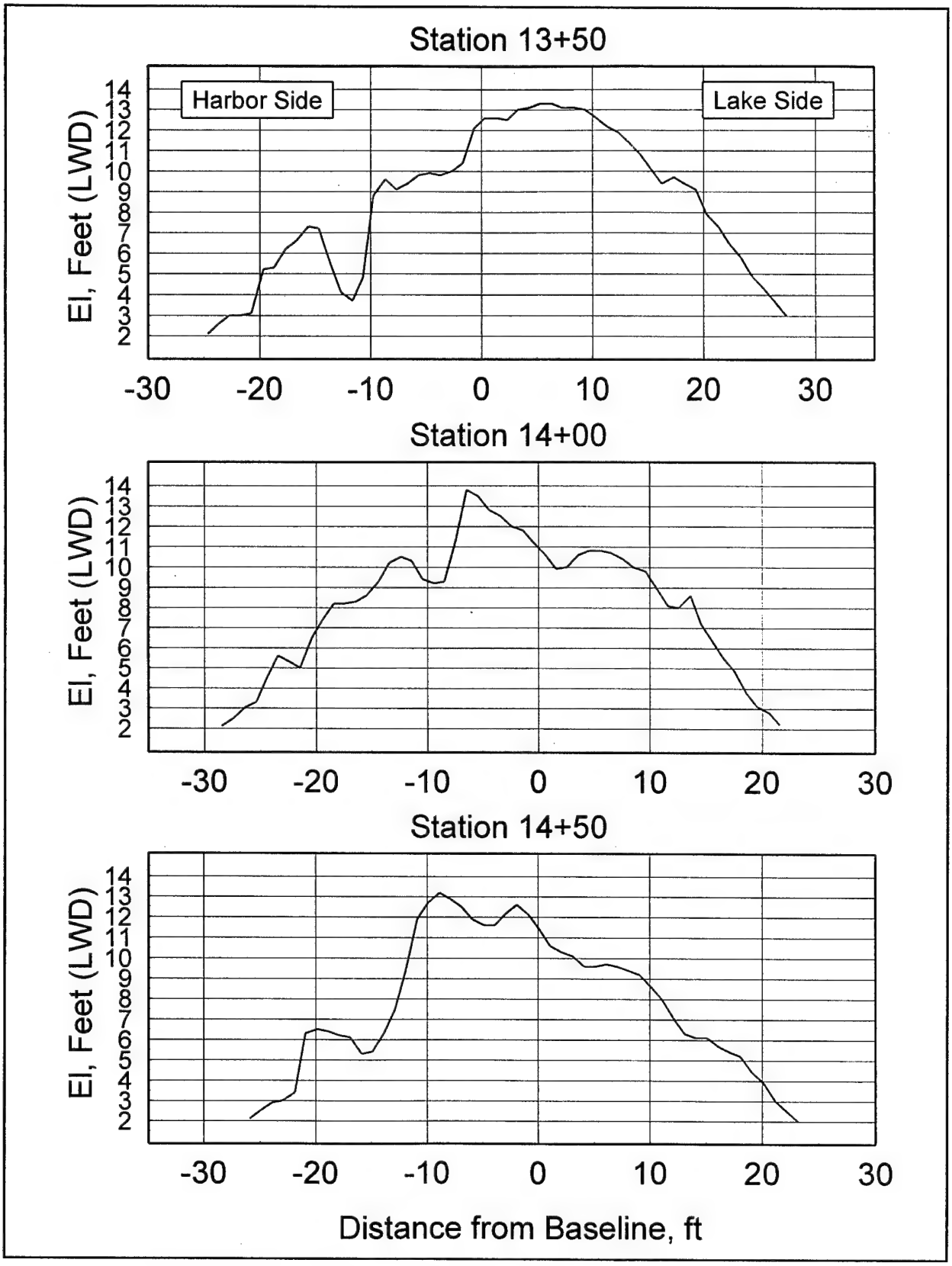


Figure B14. Cross sections of Burns Harbor North Breakwater, sta 13+50, 14+00, and 14+50

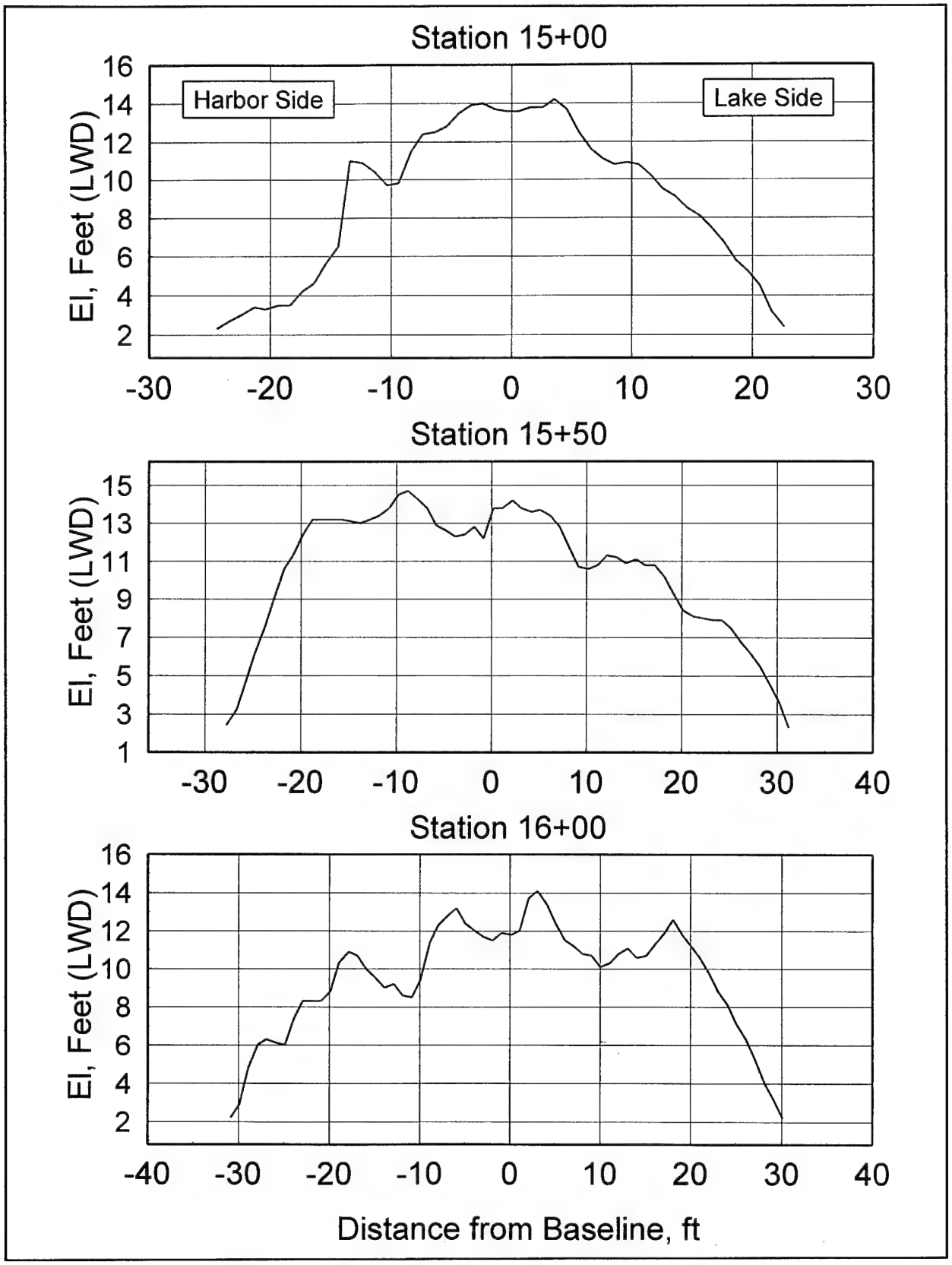


Figure B15. Cross sections of Burns Harbor North Breakwater, sta 15+00, 15+50, and 16+00

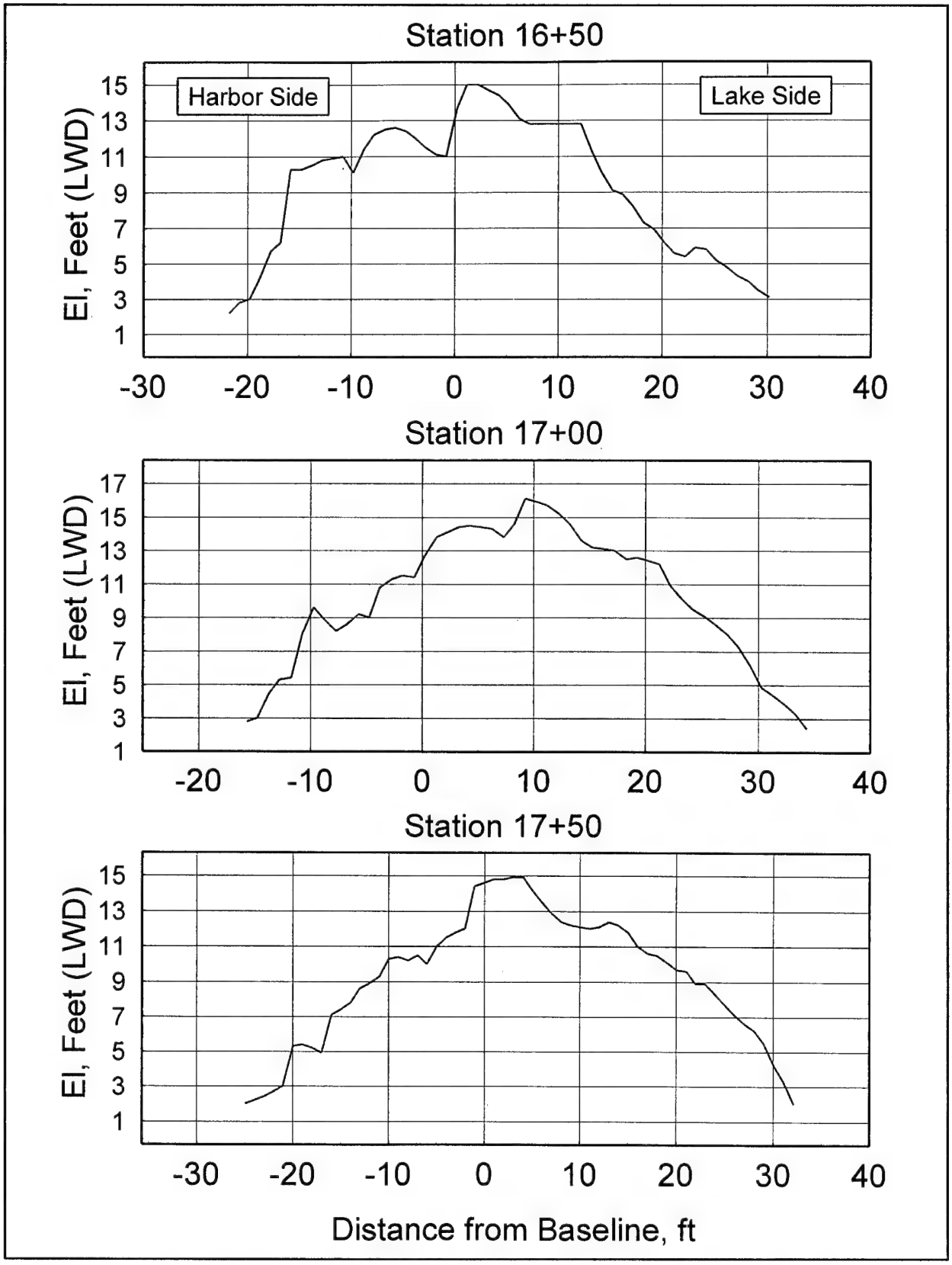


Figure B16. Cross sections of Burns Harbor North Breakwater, sta 16+50, 17+00, and 17+50

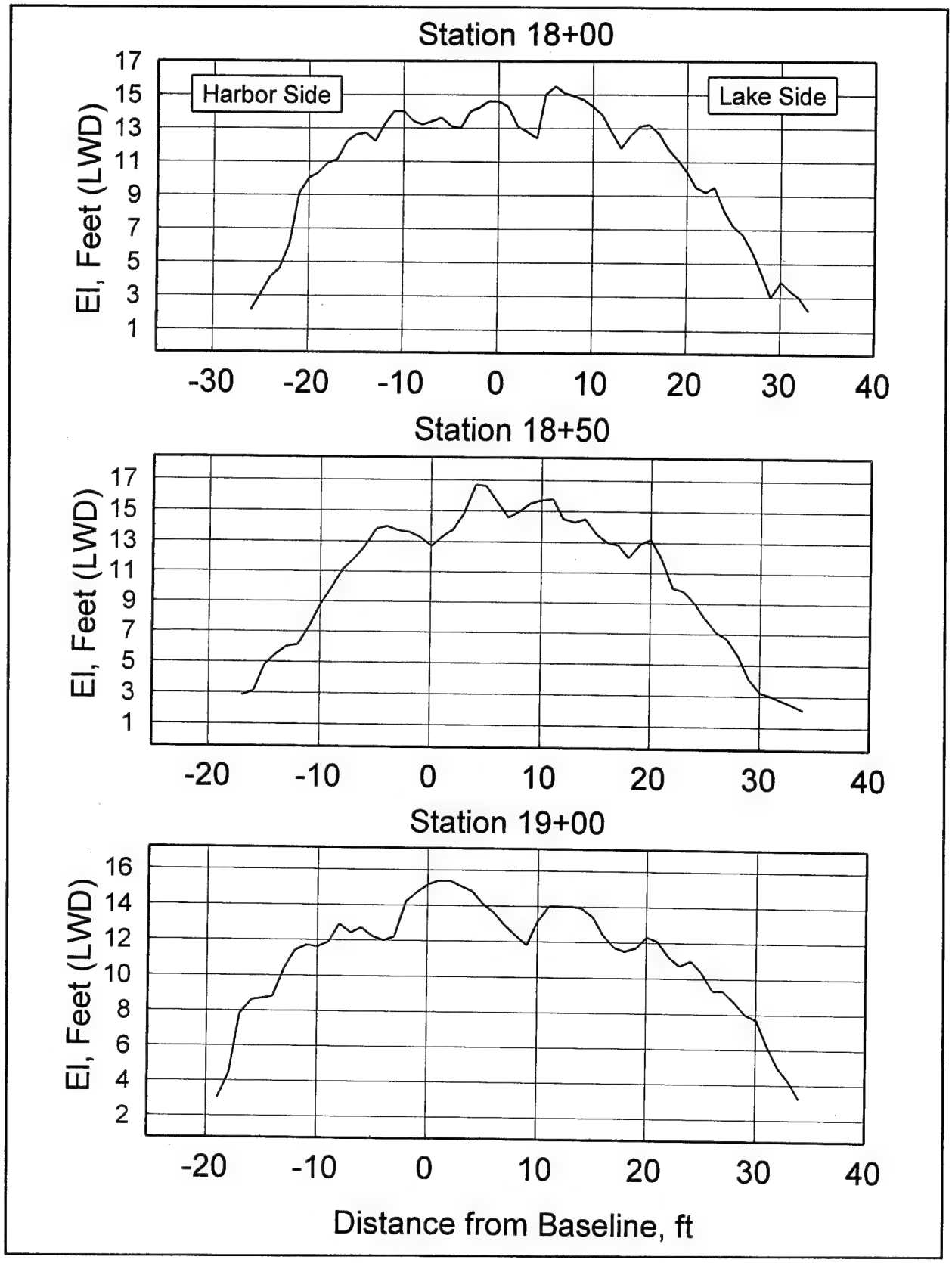


Figure B17. Cross sections of Burns Harbor North Breakwater, sta 18+00, 18+50, and 19+00

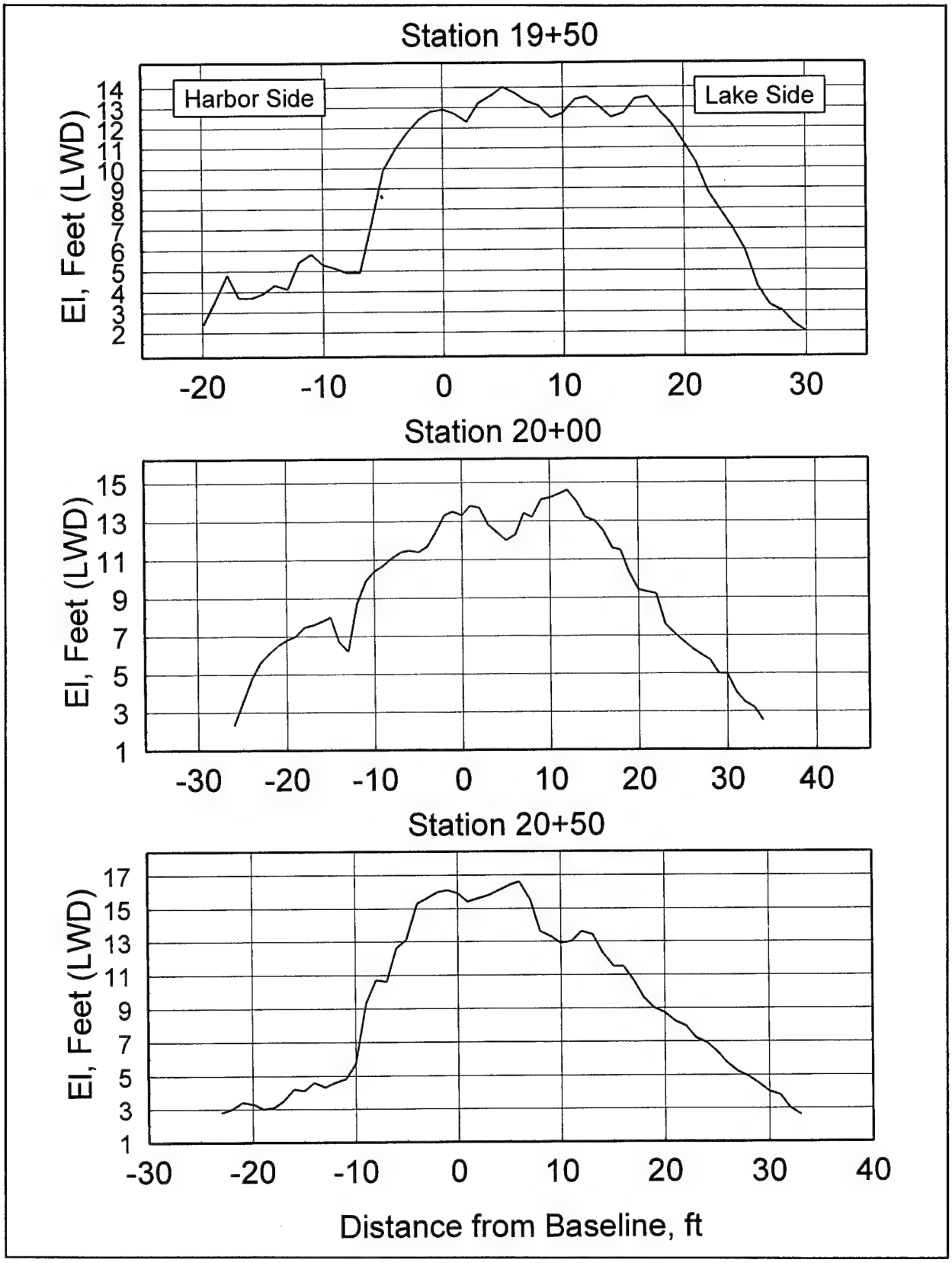


Figure B18. Cross sections of Burns Harbor North Breakwater, sta 19+50, 20+00, and 20+50

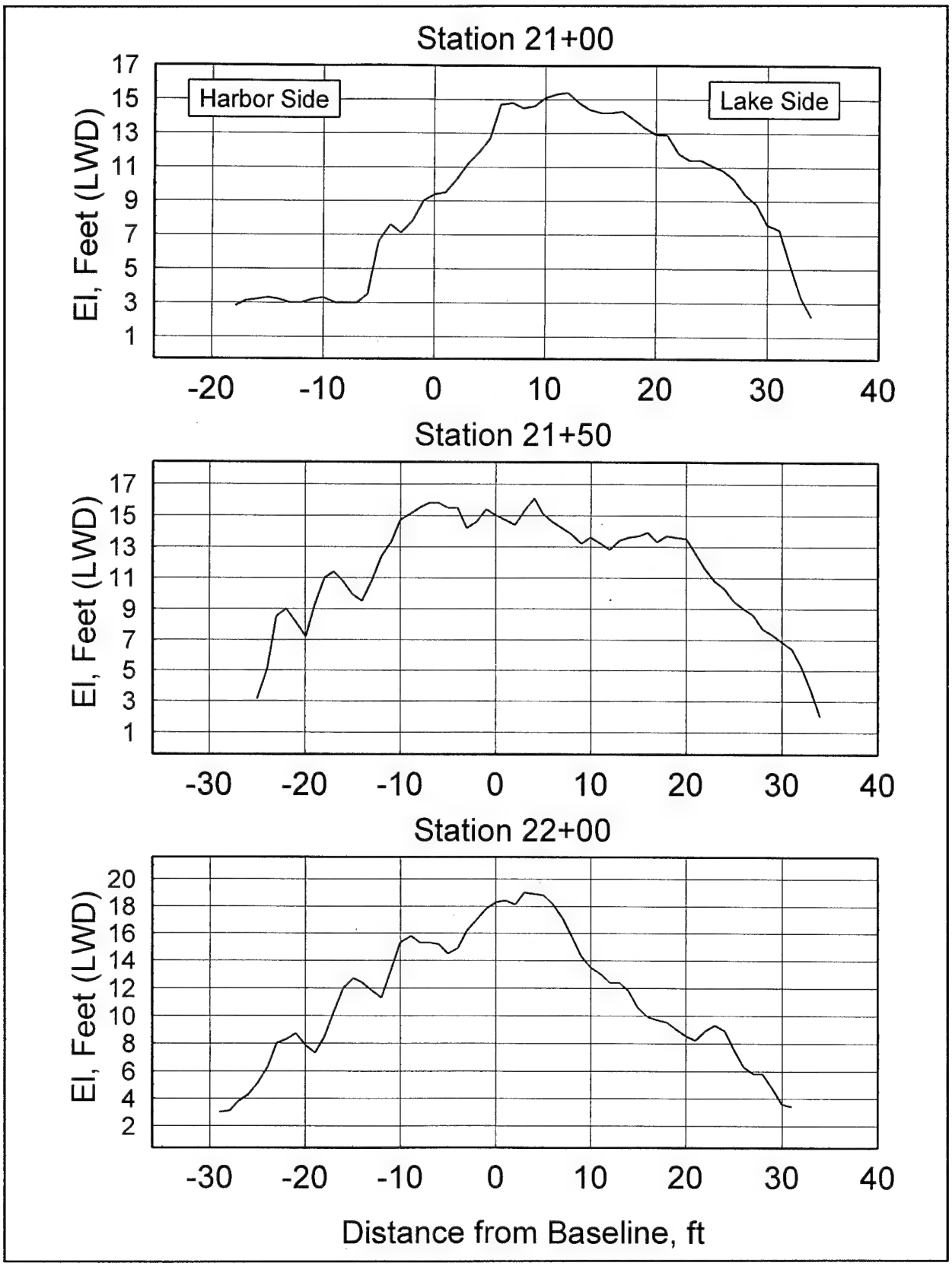


Figure B19. Cross sections of Burns Harbor North Breakwater, sta 21+00, 21+50, and 22+00

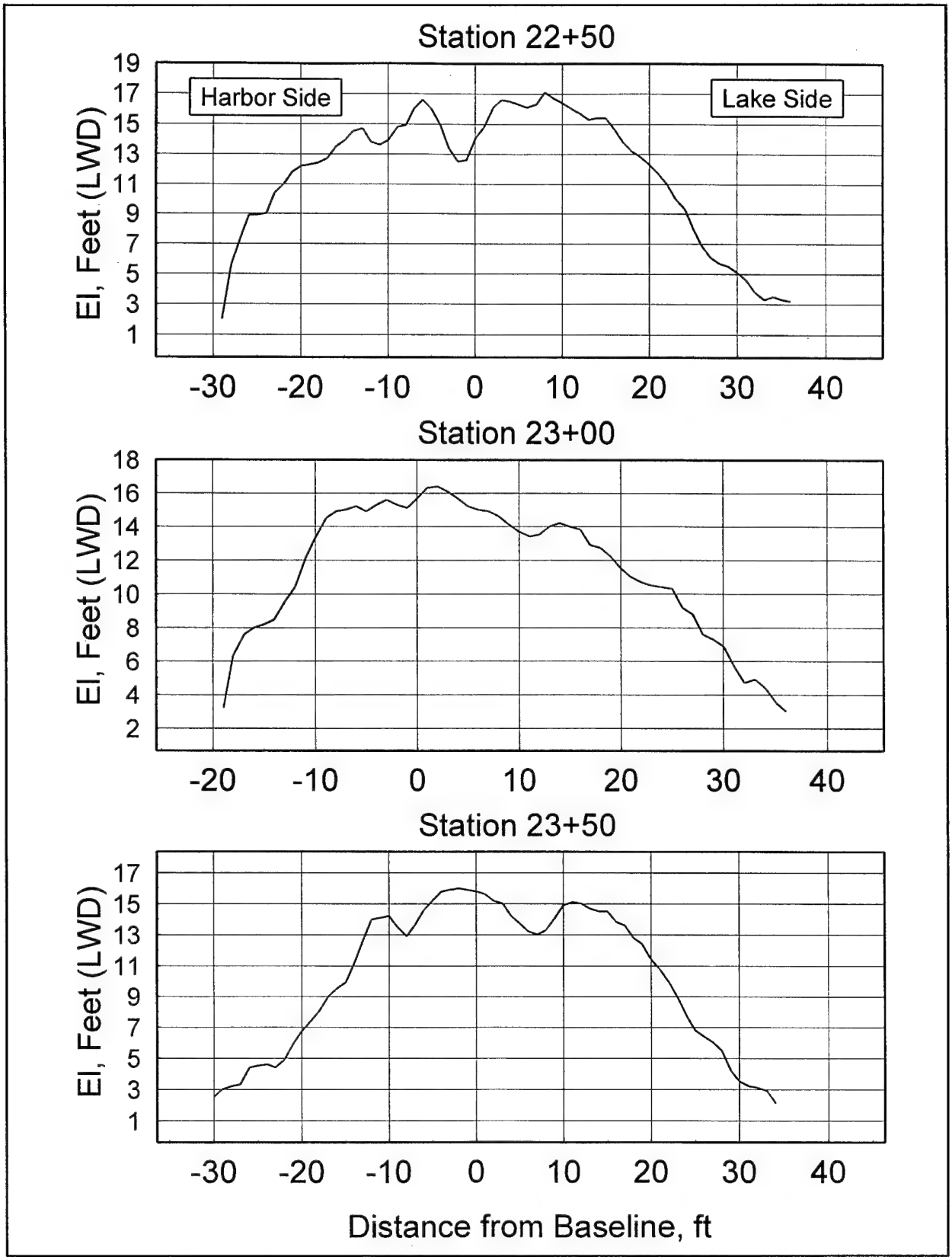


Figure B20. Cross sections of Burns Harbor North Breakwater, sta 22+50, 23+00, and 23+50

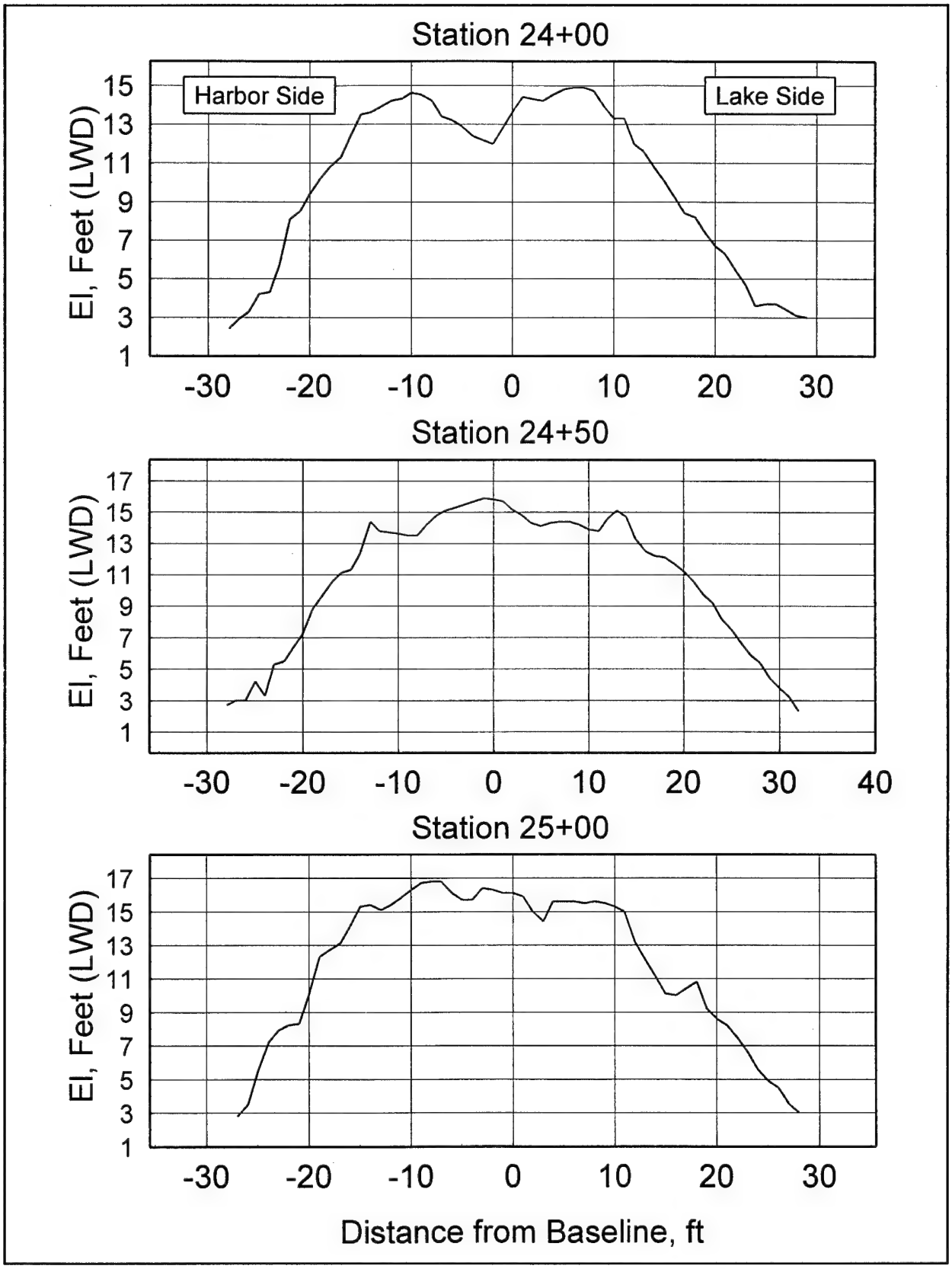


Figure B21. Cross sections of Burns Harbor North Breakwater, sta 24+00, 24+50, and 25+00

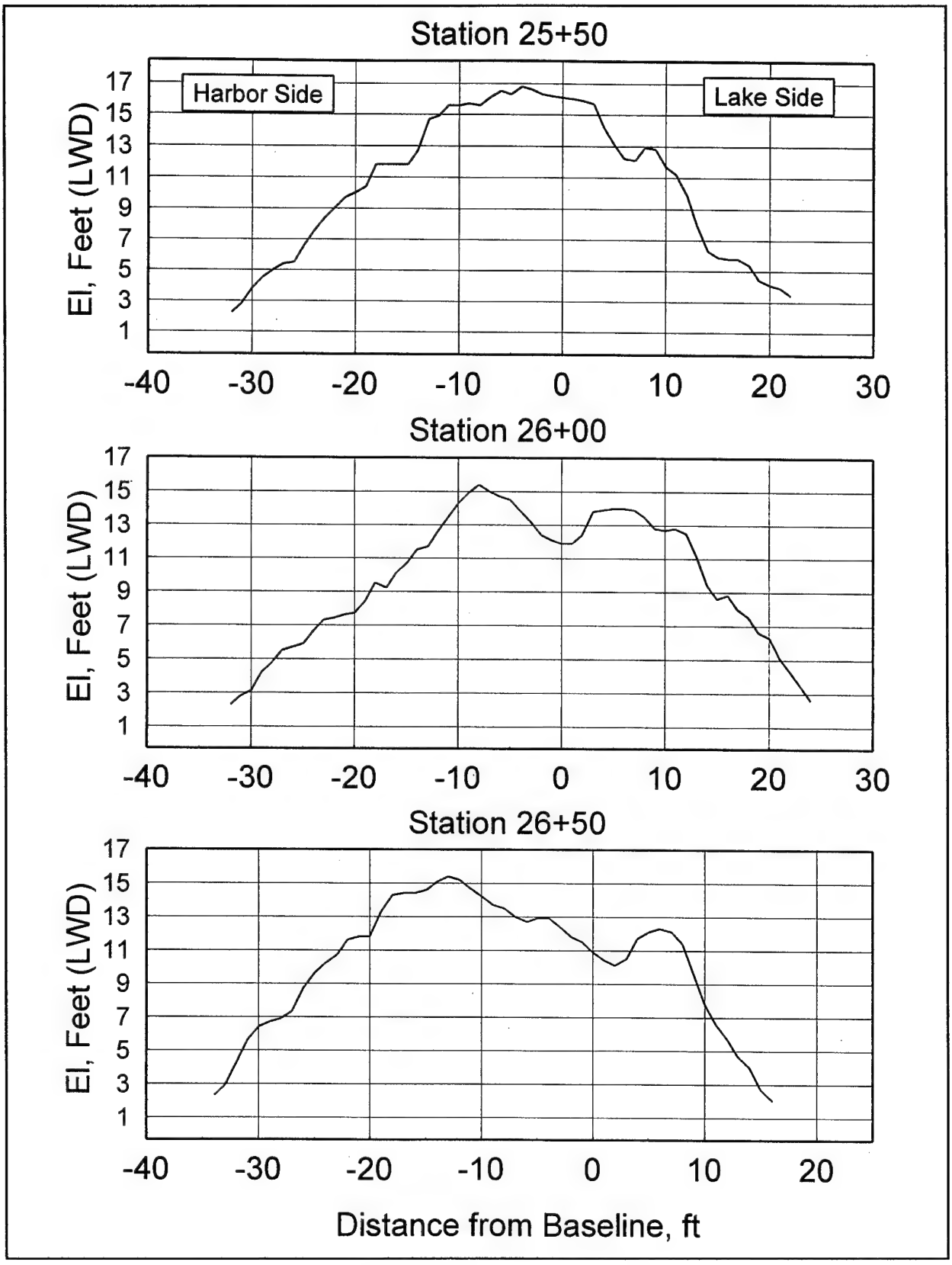


Figure B22. Cross sections of Burns Harbor North Breakwater, sta 25+50, 26+00, and 26+50

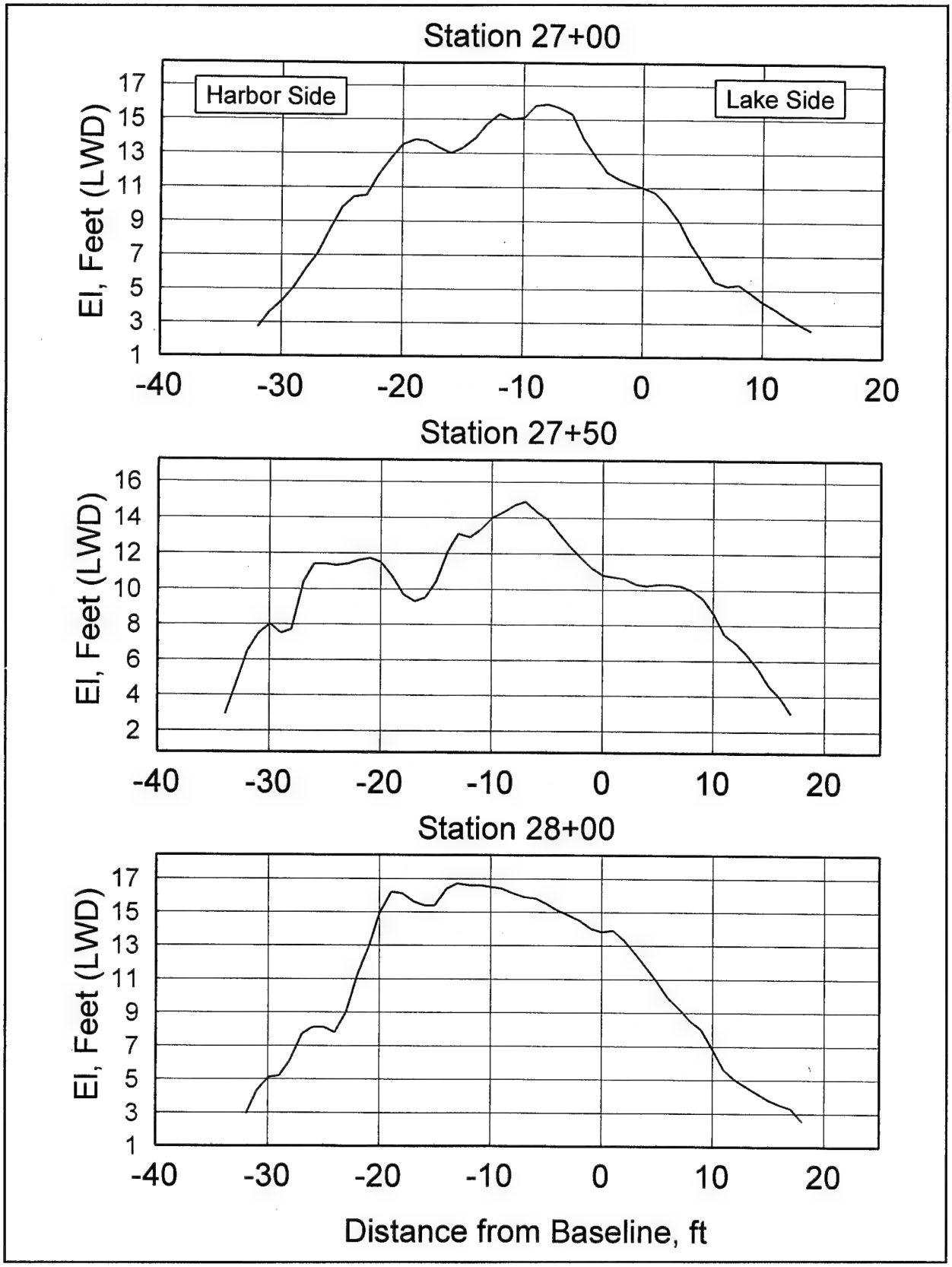


Figure B23. Cross sections of Burns Harbor North Breakwater, sta 27+00, 27+50, and 28+00

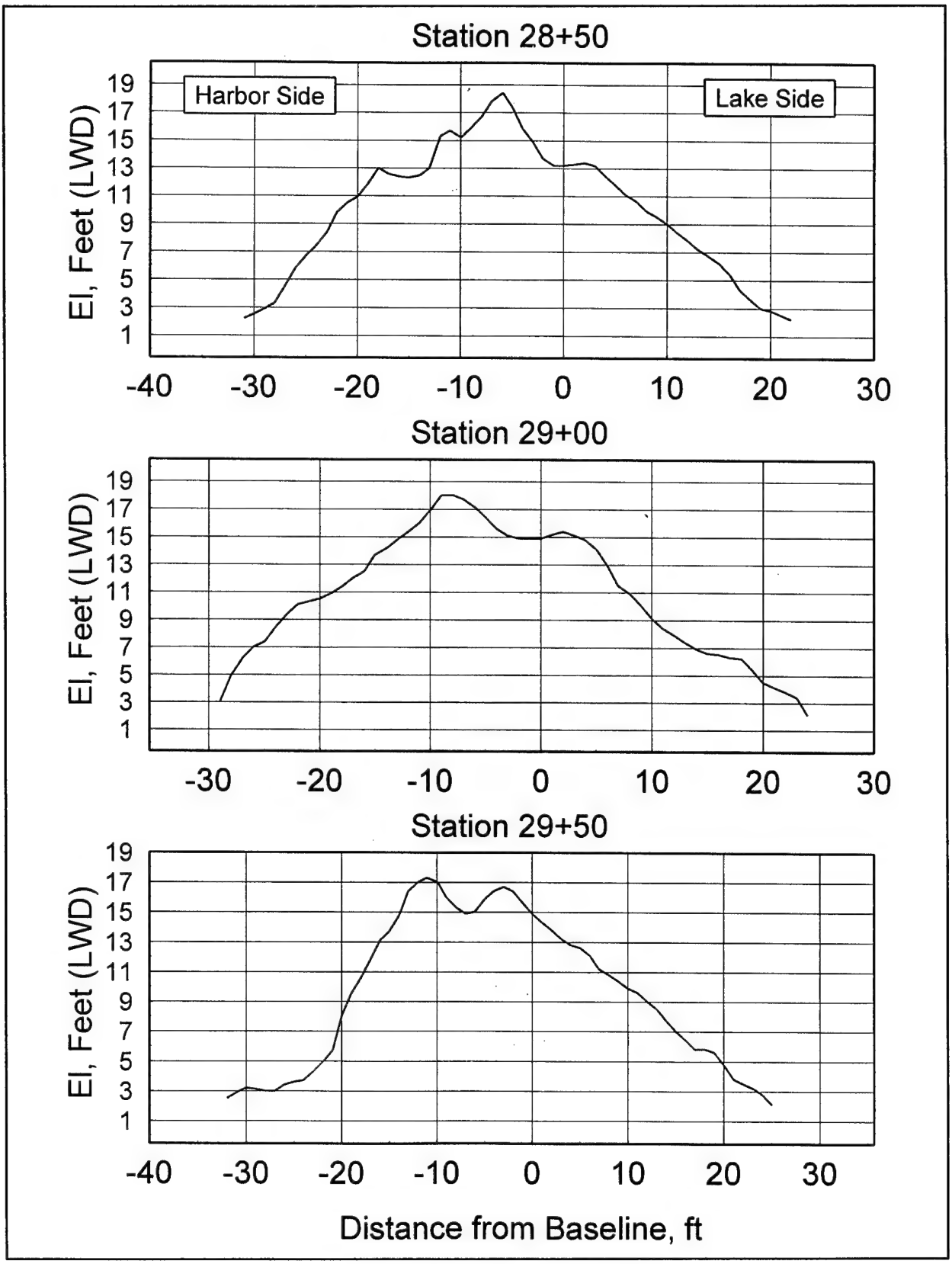


Figure B24. Cross sections of Burns Harbor North Breakwater, sta 28+50, 29+00, and 29+50

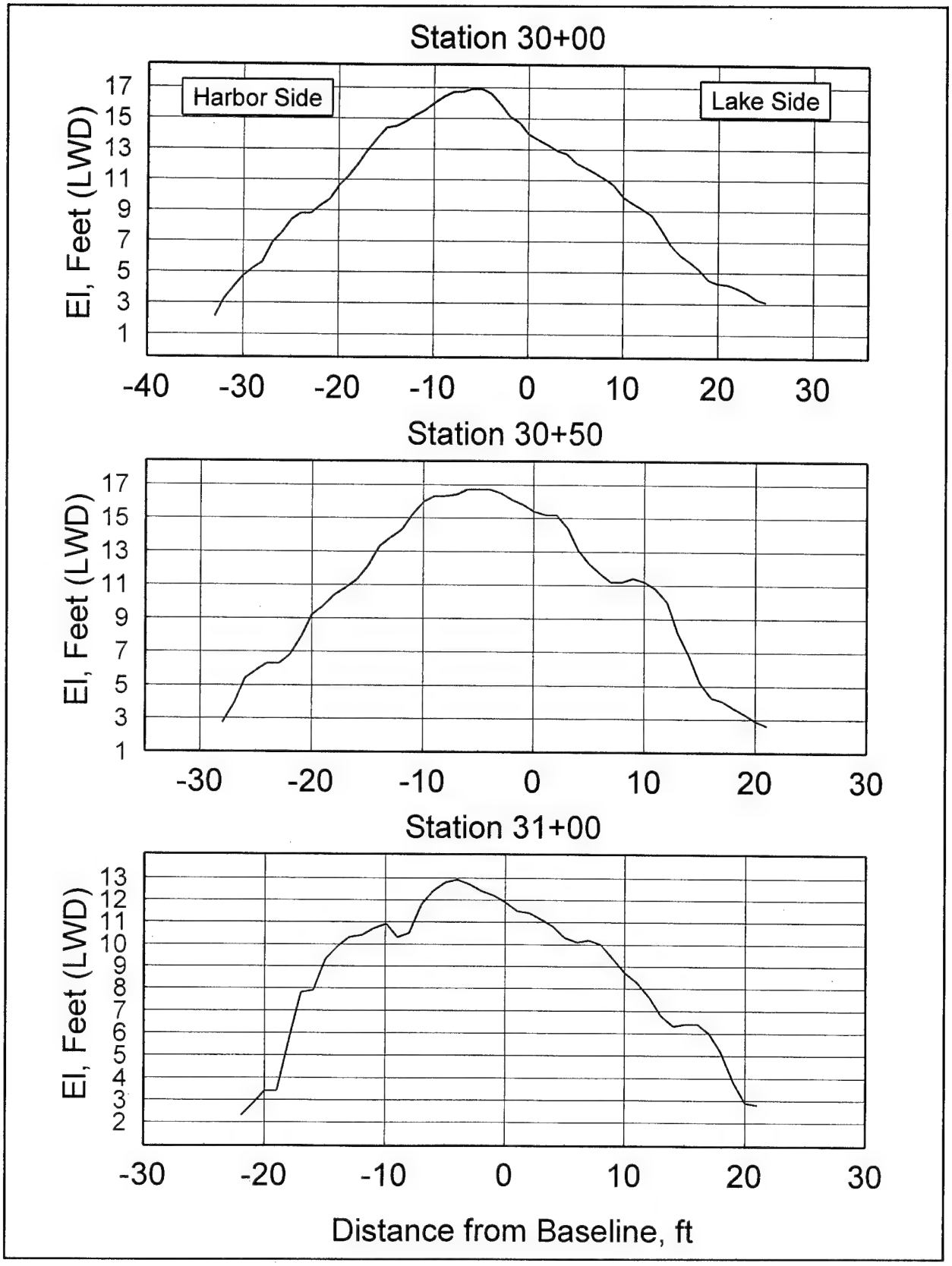


Figure B25. Cross sections of Burns Harbor North Breakwater, sta 30+00, 30+50, and 31+00

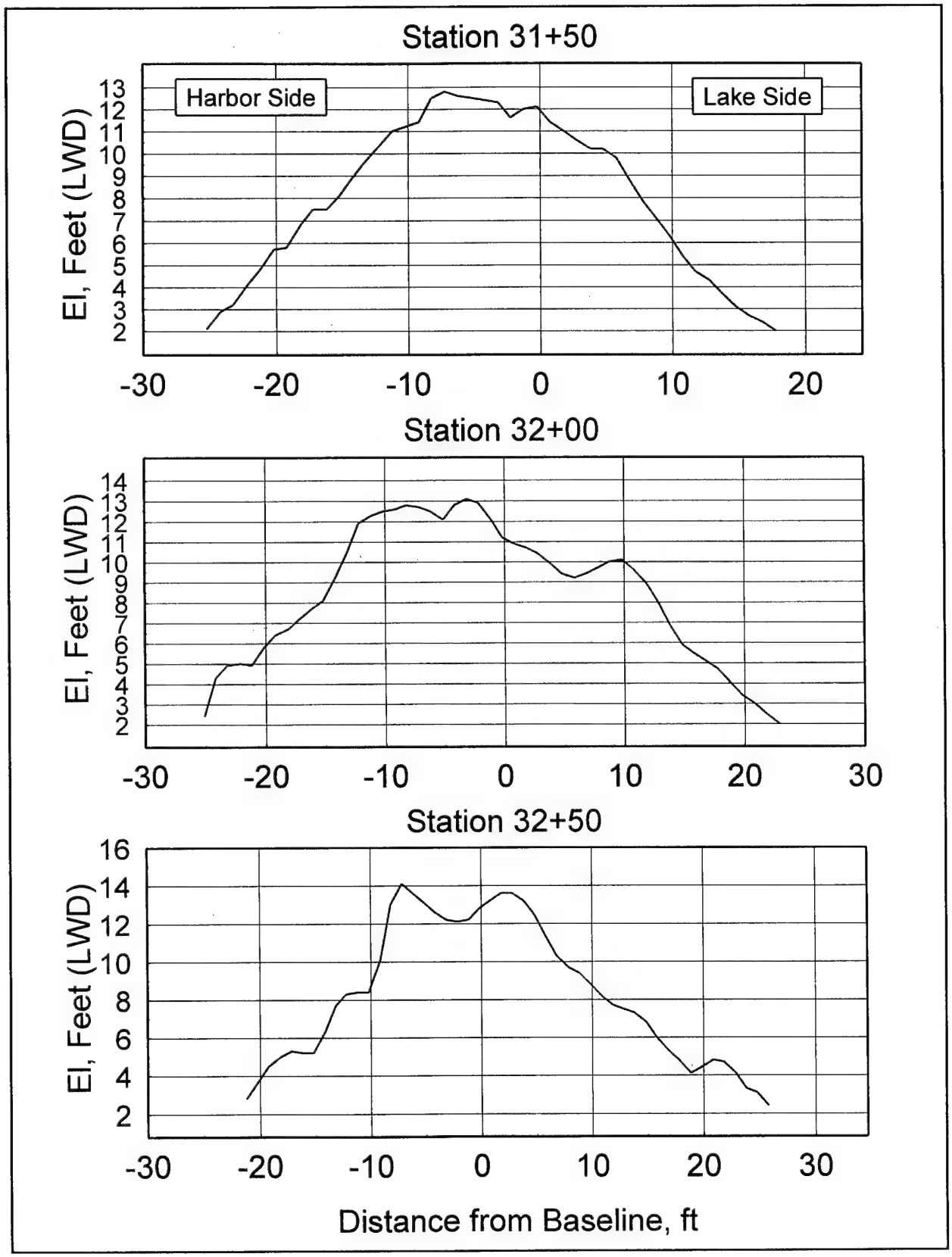


Figure B26. Cross sections of Burns Harbor North Breakwater, sta 31+50, 32+00, and 32+50

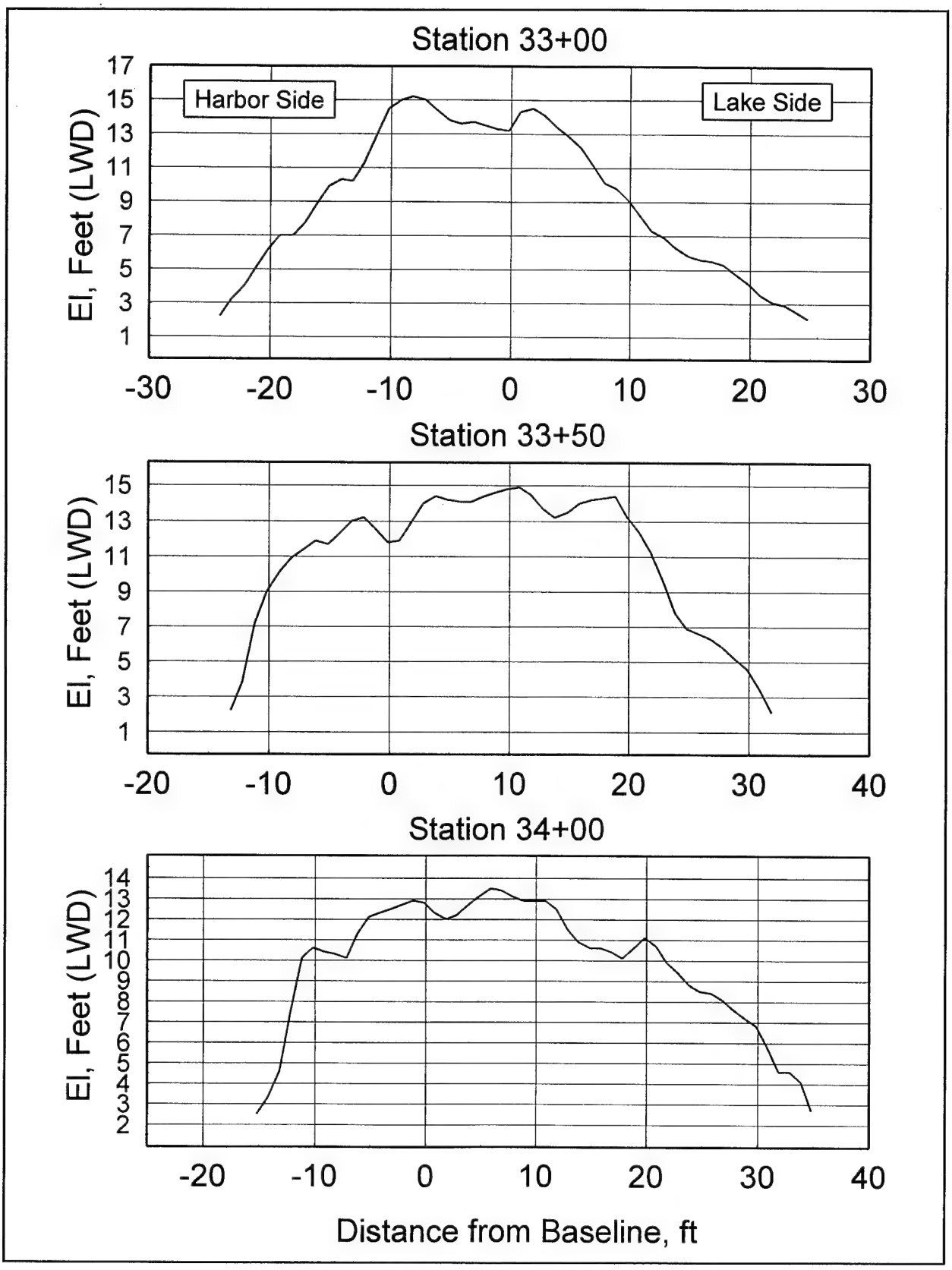


Figure B27. Cross sections of Burns Harbor North Breakwater, sta 33+00, 33+50, and 34+00

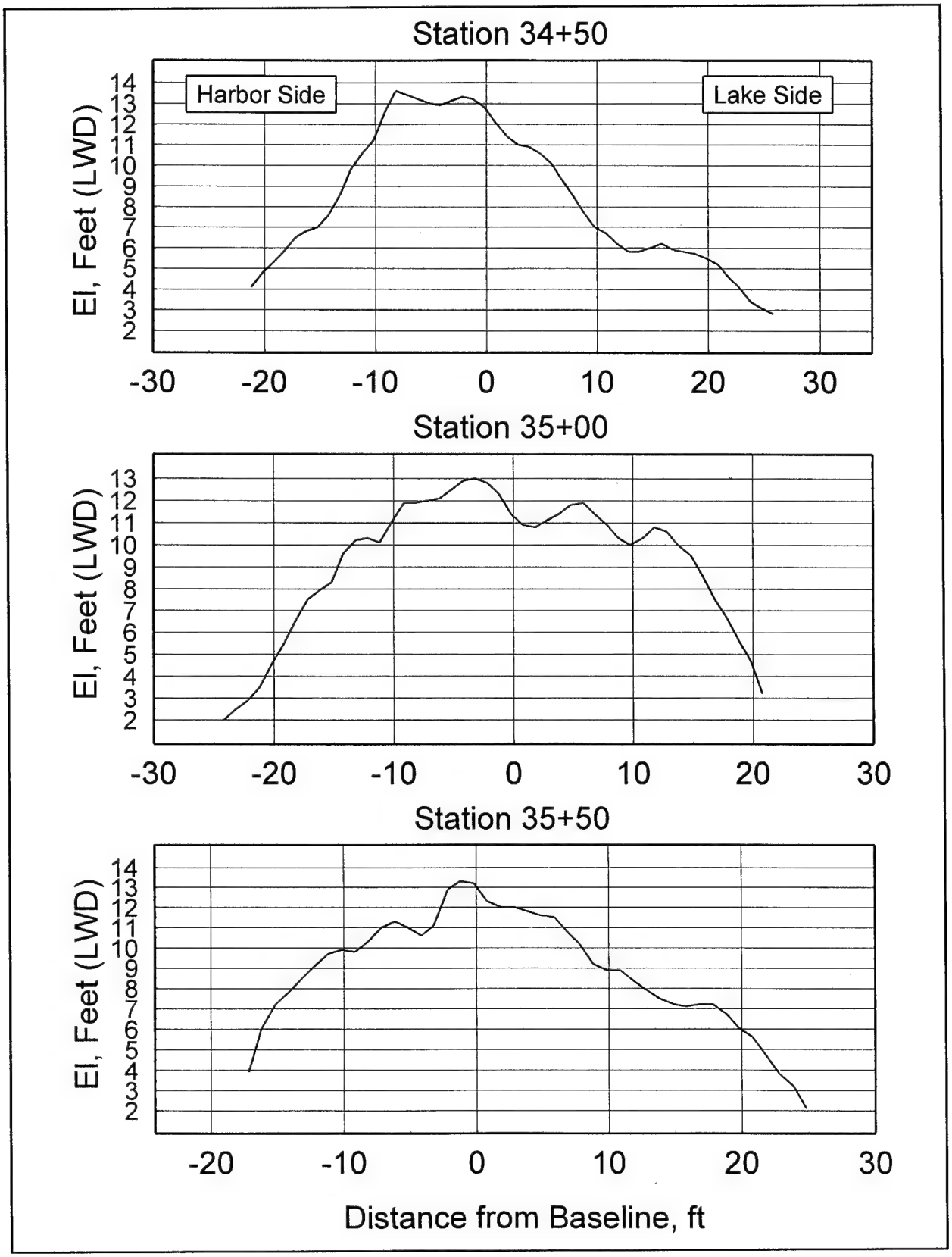


Figure B28. Cross sections of Burns Harbor North Breakwater, sta 34+50, 35+00, and 35+50

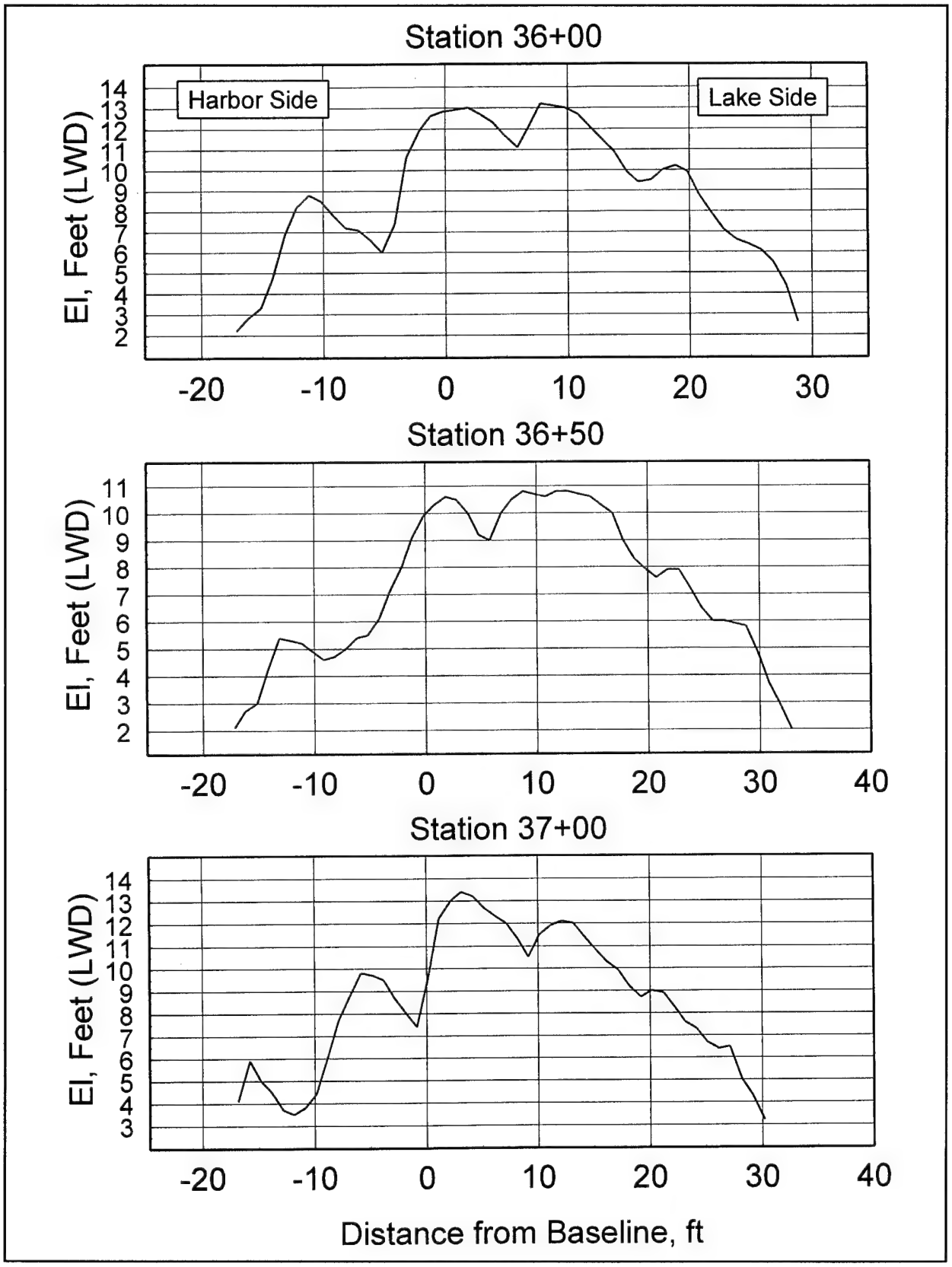


Figure B29. Cross sections of Burns Harbor North Breakwater, sta 36+00, 36+50, and 37+00

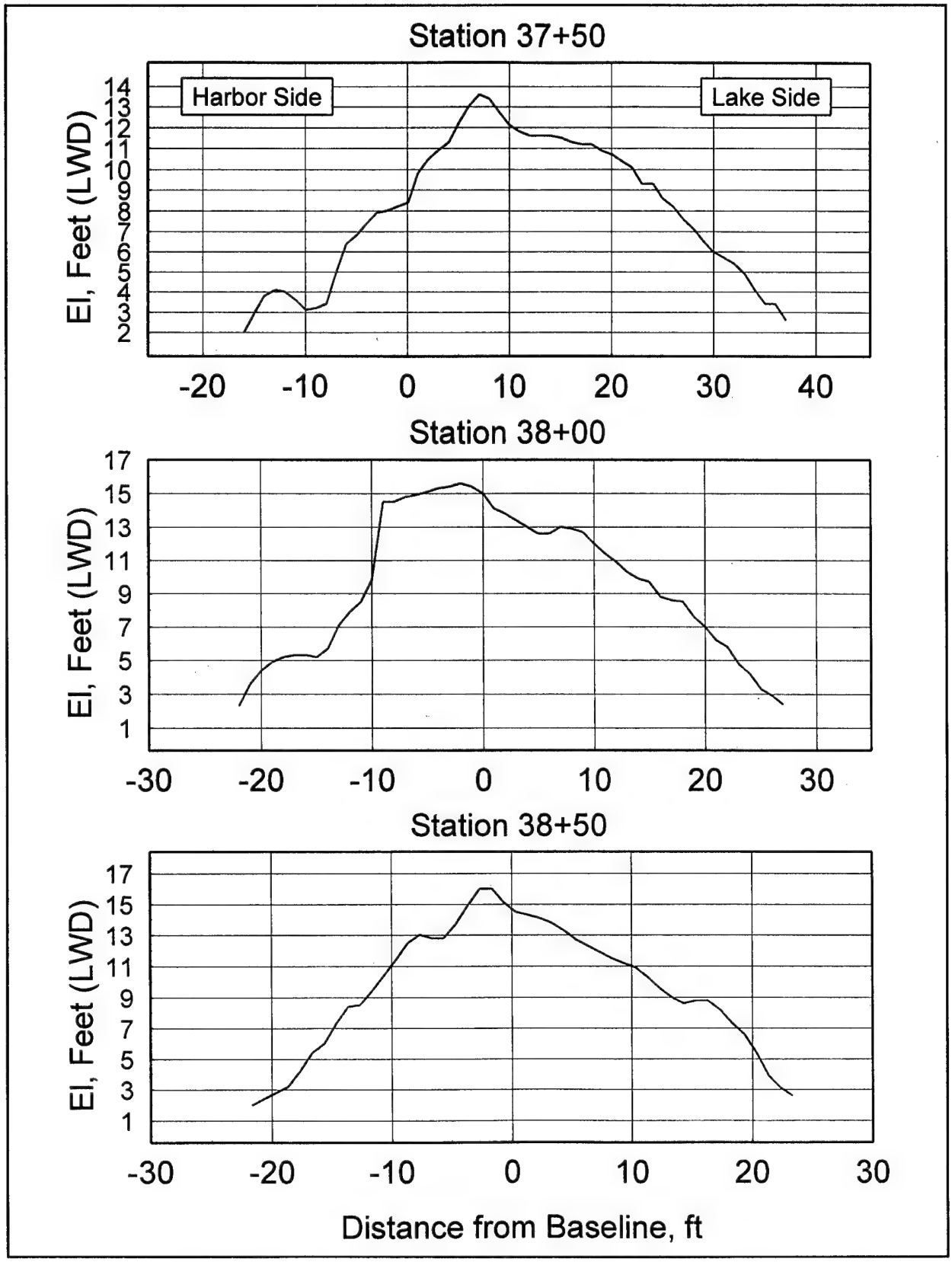


Figure B30. Cross sections of Burns Harbor North Breakwater, sta 37+50, 38+00, and 38+50

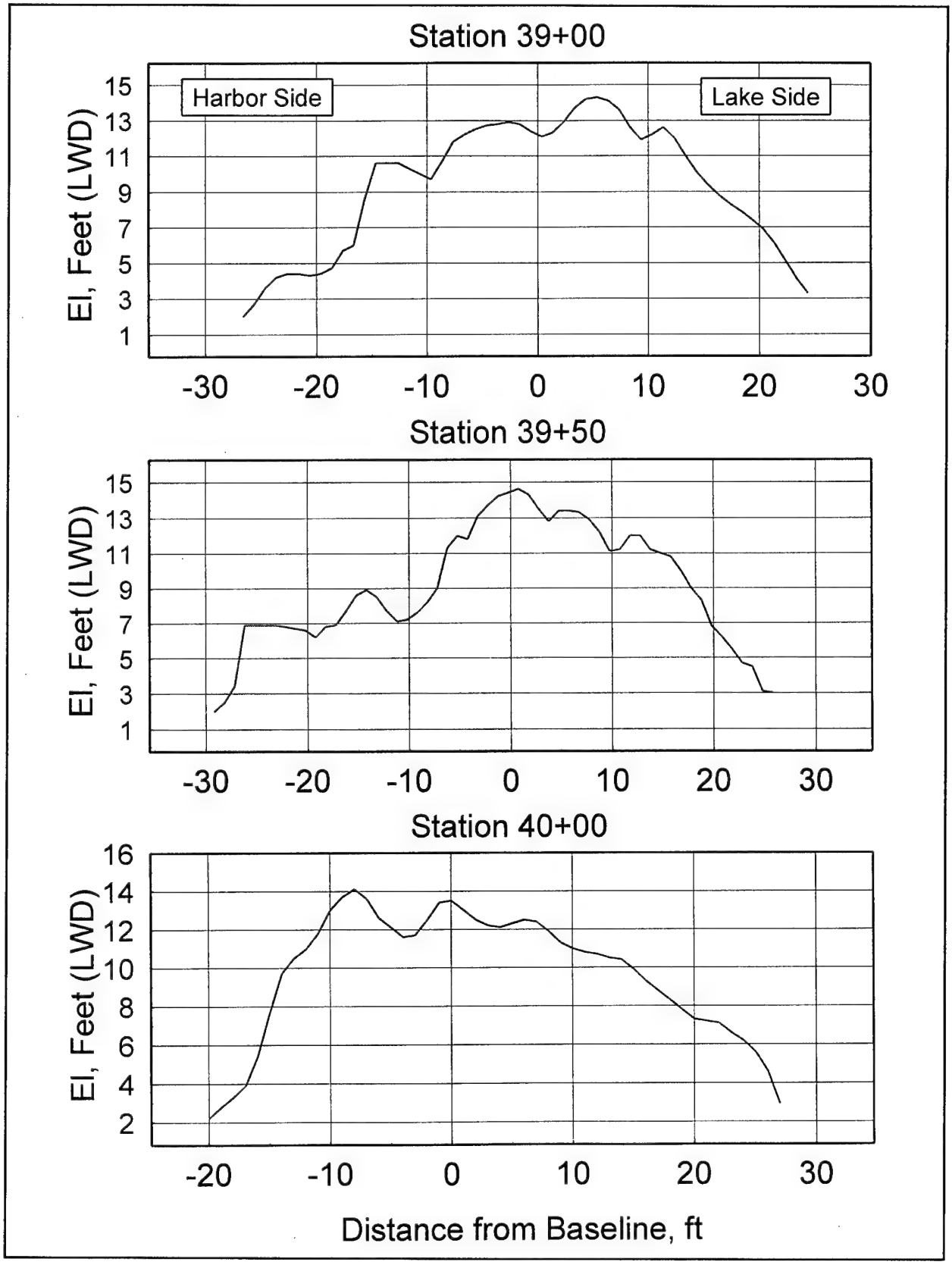


Figure B31. Cross sections of Burns Harbor North Breakwater, sta 39+00, 39+50, and 40+00

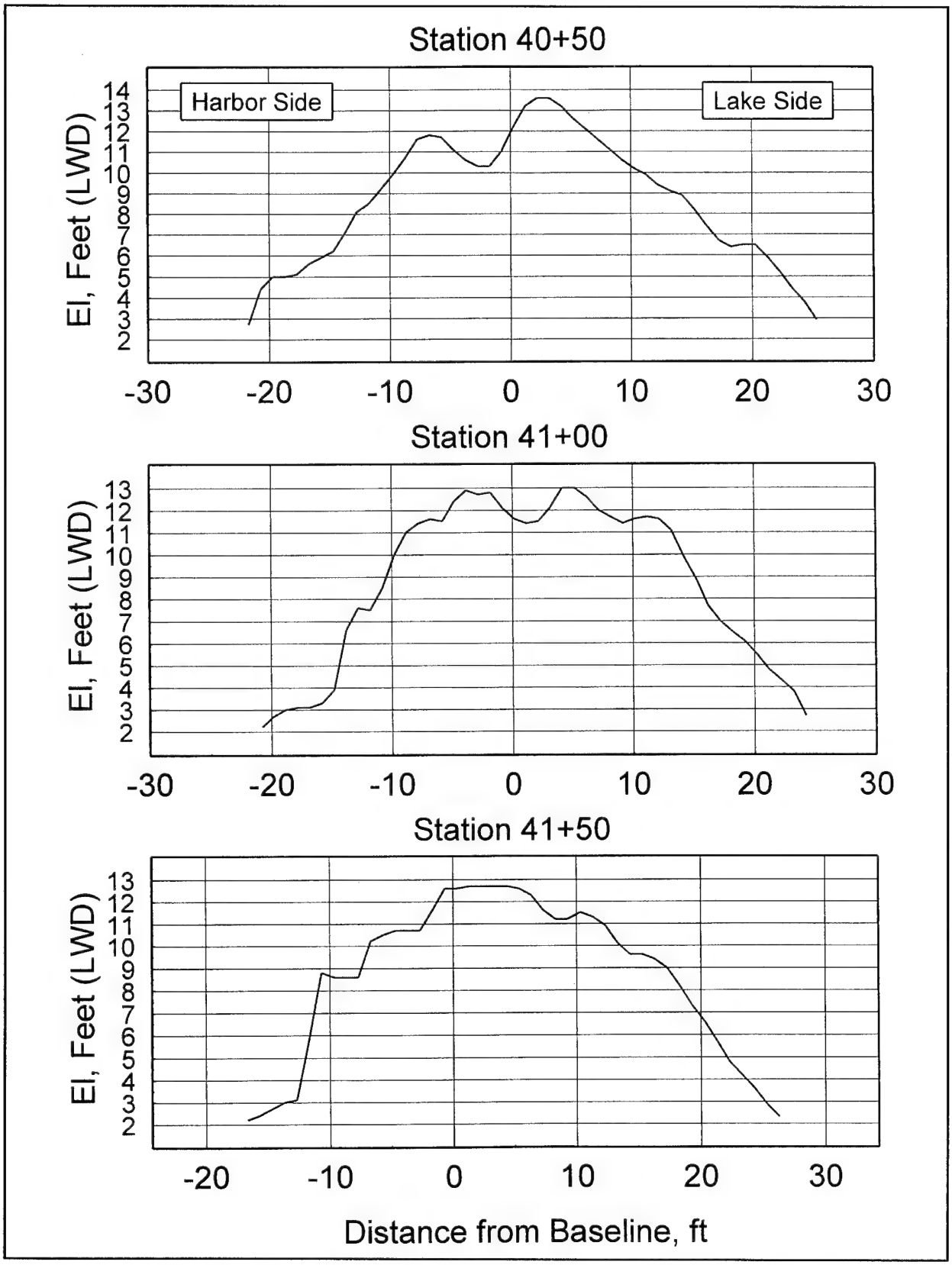


Figure B32. Cross sections of Burns Harbor North Breakwater, sta 40+50, 41+00, and 41+50

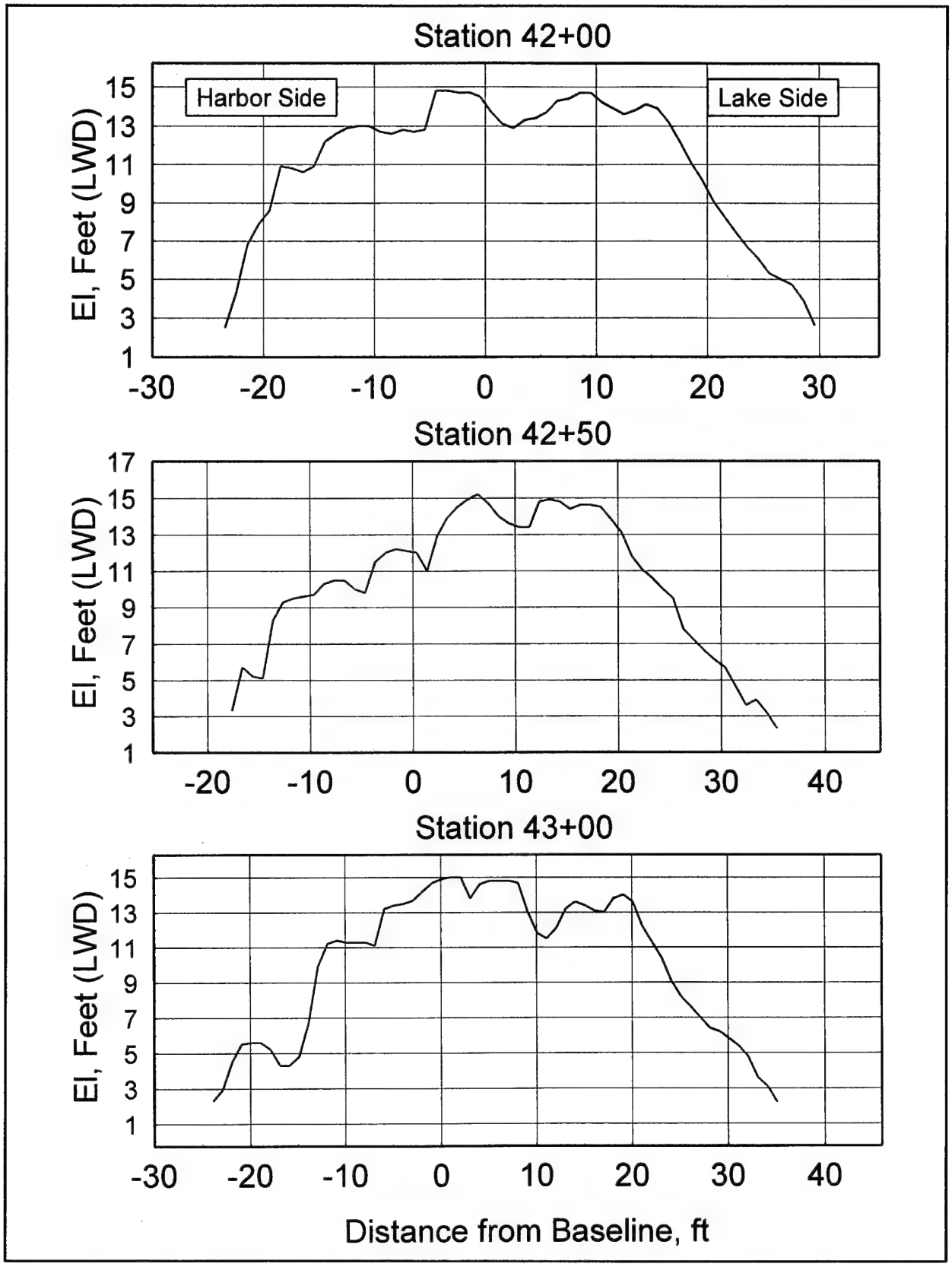


Figure B33. Cross sections of Burns Harbor North Breakwater, sta 42+00, 42+50, and 43+00

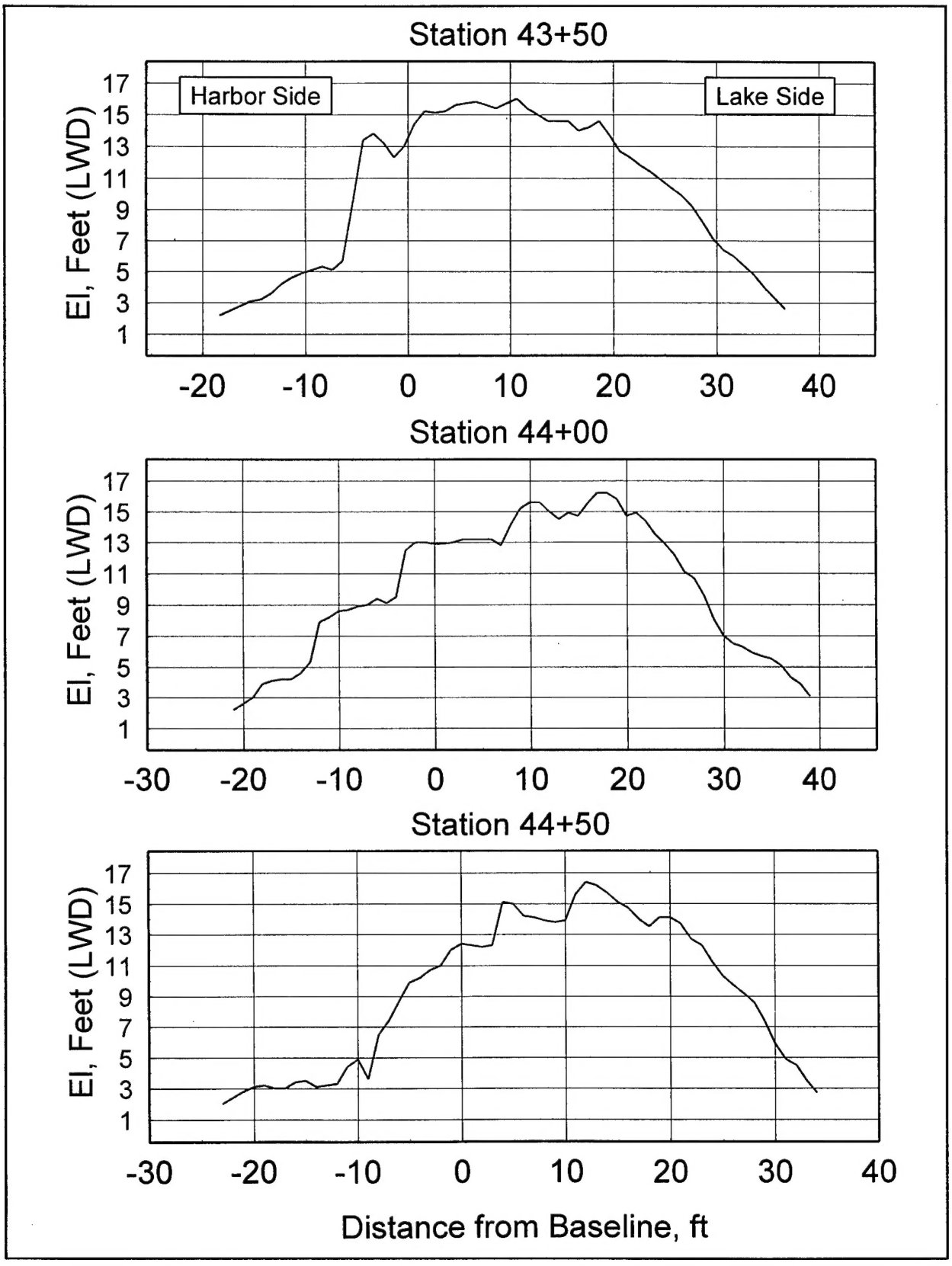


Figure B34. Cross sections of Burns Harbor North Breakwater, sta 43+50, 44+00, and 44+50

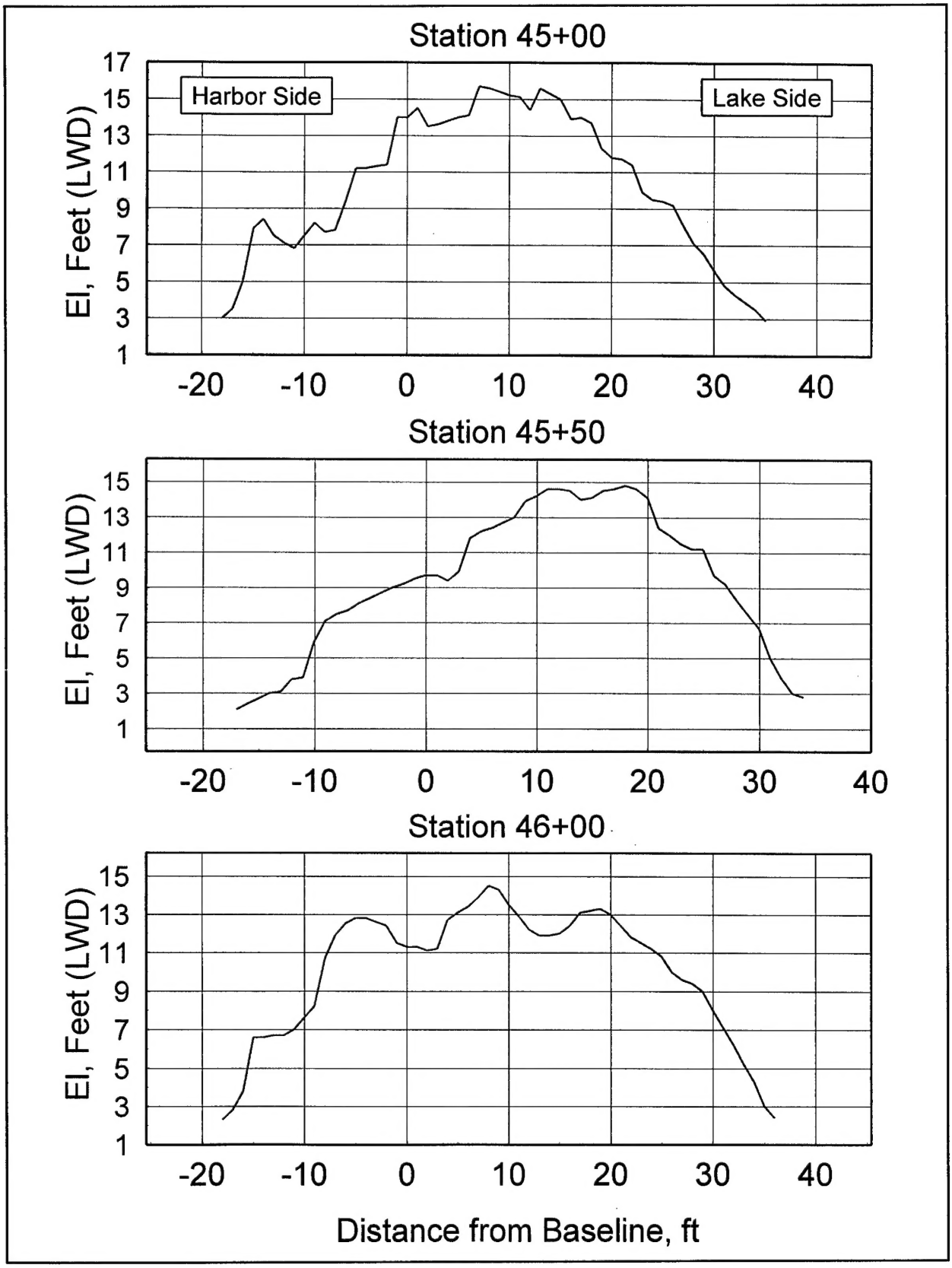


Figure B35. Cross sections of Burns Harbor North Breakwater, sta 45+00, 45+50, and 46+00

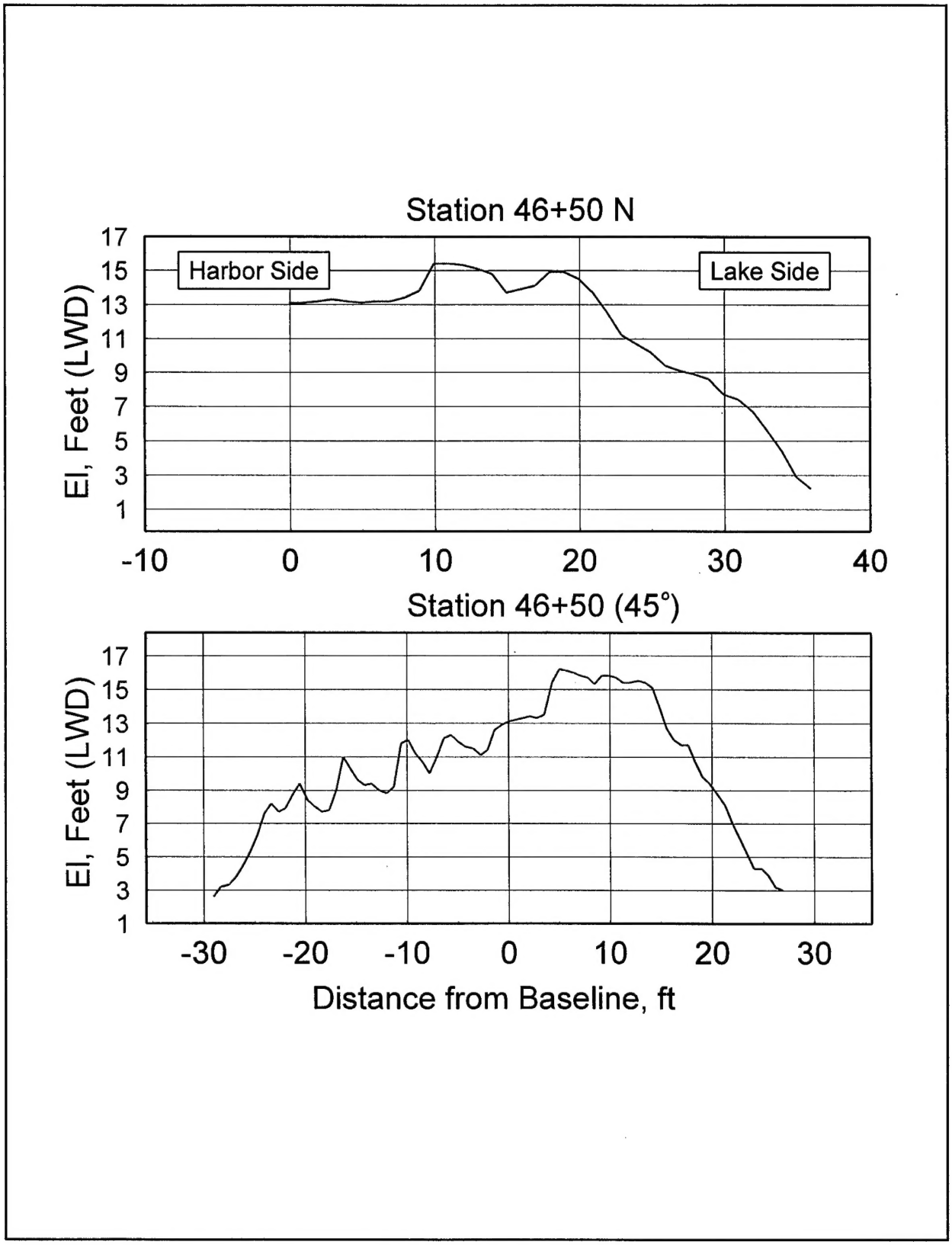


Figure B36. Cross sections of Burns Harbor North Breakwater, sta 46+50 N and 45+50 (0.8 rad (45 deg))

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13. ABSTRACT ***(Maximum 200 words)***

Under the Periodic Inspections Work Unit of the Monitoring Completed Coastal Projects Program, base level conditions have been established for the above-water armor stone on the Burns Harbor North Breakwater. The positions of armor stone over the 1,414-m (4,640-ft) length of the breakwater have been defined through limited ground surveys, aerial photography, and photogrammetric analysis. Contour maps of the breakwater as well as cross sections of the structure have been developed. In addition, a database of broken armor stones has been established. The site will be revisited periodically in the future and the long-term structural response of the breakwater to its environment will be tracked. The periodic data sets will be used to improve knowledge in design, construction, and maintenance of the existing structure as well as proposed future coastal projects.

14. SUBJECT TERMS

Aerial photography	Burns Harbor, IN	Photogrammetry
Armor stone	Orthophotography	Stereo pairs
Breakwaters	Periodic inspections	Stone deterioration

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